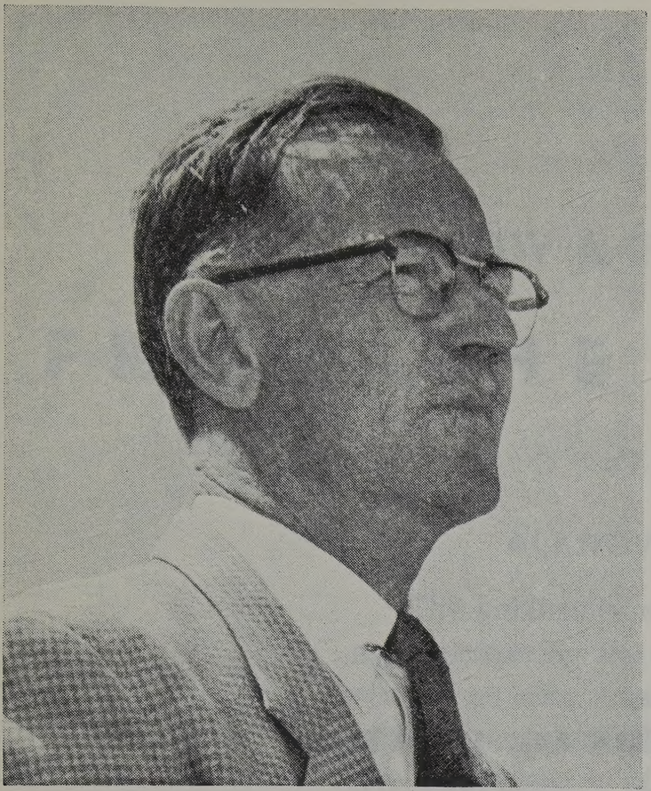
FROM THE GROUND UP



About the Founder

A pilot for thirty years, a veritable encyclopedia of Air Regulations and navigational data, and the author of millions of words on aviation, Alexander Forsyth MacDonald died on the first day of June 1965.

'Sandy' MacDonald never let his wide experience permit foregone conclusions or second hand information cloud his writing. Any fact that he committed to paper was checked and double- checked by recognized authority. Because of this meticulous care the book 'From the Ground Up' has become the reference manual of hundreds of flying schools and clubs in some 28 countries around the world.

Sandy MacDonald learned to fly at the Curtiss-Wright Flying School, Newport News, Virginia, in 1916 and saw active service as a fighter pilot in the Royal Naval Air Service on the Western Front. In combat over Passchendaele in 1917 he was seriously wounded, but he returned to the fray as an R.A.F. Instructor with the rank of Captain.

He served in the R.C.A.F. between 1927 and 1932, during which time his flying duties embraced forestry patrols, air survey, freight and transportation missions, including the first official Air Mail flight from Chesterfield Inlet to Fort Churchill.

Following this peace-time period in the Service, Sandy spent several years as a civilian pilot on charter and demonstration work, mainly in Ontario, Quebec and in the United States. Eventually in 1937 he settled down as Vice-President of Aviation Service Corporation, aeronautical research claiming his attention just prior to World War II, when he teamed up with Adam Craigon, an aeronautical engineer.

In 1939 he became director of the Patterson & Hill Aircraft Company, and took on the duties of Chief Ground Instructor; he was responsible for the graduation, in ground school subjects, of more than thirty-five percent of the Elementary Flying Instructors engaged in the British Commonwealth Air Training Plan. Later he was appointed Chief Air Navigation Instructor of No. 20 Elementary Flying Training School, Oshawa, in which capacity he originated the first practical Navigation Flight to be established in a Canadian flying school. It was during this period that 'From the Ground Up' was really born, for later on the notes that he had made for these courses served as the foundation upon which he developed this manual.

In the latter stages of the War, Sandy became a Trans-Atlantic Ferry Pilot with the Royal Air Force. At the age of forty-five he was flying the ocean at a time when aids were relatively scarce and the trips were still a very perilous adventure.

Sandy joined de Havilland Canada as Sales Manager when the Company was building the "Fox Moth" for the bush conditions that he knew so well. He became Public Relations Manager some ten years later, and retired in 1963 to take on 'From the Ground Up' as a full-time occupation.

That year Sandy received the Writing Award of the Aviation/Space Writers Association of America for his work on this manual, described as "excellence in content and meritorious authorship of an aviation/space manual".

In 1964 he was honoured by the Sherman Fairchild International Flight Safety Award. Once more his authorship of 'From the Ground Up' was recognised with a citation that referred to "his extraordinarily thorough and well written contribution to the art of flying safely".

This popular ground school manual will forever be a timely and fitting memorial to a dedicated instructor's Instructor.

C. H. 'Punch' Dickins,

C. H. 'Punch' Dickins

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SANDY A. F. MacDONALD'S

FROM THE GROUND UP

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The publishers wish to express grateful appreciation for the assistance and co-operation which has been received in the preparation of this manual to officials of the Civil Aviation Branch, Ministry of Transport, and to dozens of flying instructors and ground school lecturers from all across Canada who have submitted recommendations to improve this manual.

AWARDS

1963

AWA Writing Award
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Presented by
The Aviation/Space Writers Association
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FSF

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Administered by
The Flight Safety Foundation
of America

OFFICIALLY APPROVED BY THE AIR ATAC TRANSPORT ASSOCIATION OF CANADA

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So You Want To Be A Pilot?

Among other things, one of the problems a pilot should tackle is learning to fly. Countless deluded young people, yearning for a career in aviation, have the sadly mistaken idea that that is all there is to it. A few hundred hours of patient application, the acquired ability to handle a flying machine with skill and ease — and presto! . . .wings and gold braid. To those misguided young people I say, "Go back to the farm before Dad changes his mind." There is no easy way.

Ability to fly is a step in the right direction — but the most elementary one in our whole curriculum. In a few years Junior will learn to fly before he graduates from high school. Countless millions will line up once every year all over the world to renew their pilot's certificates — much the same as motorists do today. There is no pay-off on arts or crafts which are the common accomplishment of the masses. A transport pilot is, and always will be, however, a highly sought, highly paid individual specialist — because he is a master craftsman in his trade.

"Well," you ask, "what has he got that I haven't got?" That's exactly what we propose to tell you in these pages. "Weather sense", for one thing, a knowledge of line squalls and thunderstorms and icing conditions — of stable and unstable air masses — of cold fronts, and dewpoint, and all the odds and ends that go to make up the science of meteorology.

He is an expert navigator, and understands how to plot headings and bearings. He has an expert knowledge of wind and drift problems. He is thoroughly conversant with such things as Azimuth, Isogonic lines, and Great Circle Tracks. And right here, let us definitely emphasize that the latter in no way refers to those affairs on which railway trains run to and fro. The bird who specializes in following railway lines around from place to place is not a navigator, but an opportunist. When the tracks go in a tunnel, he is lost and has to go home. His only means of getting across open water is a matter of pure good fortune — if there happens to be a ferry boat going his way!

A transport pilot knows his plane and his engine. The lives of his passengers depend on their airworthiness as much as on his own skill and knowledge — so he conscientiously superintends their service and maintenance. He understands fuel-air ratio, and knows how to get the last ounce of power and the most miles out of a given volume of fuel. He is familiar with all the invisible forces and couples that act on an airplane in flight and he knows when his airplane has been subjected to any abnormal stresses that may lead to a structural strain.

In other words, he is the type of skipper one flies behind with utmost confidence — based on assurance that he not only rates officially as a Grade A Pilot and Navigator, but he is a thorough technician as well, completely versed in every last-minute detail of his profession both on the ground and in the air.

"But," you may point out, "I have no ambition to become an airline captain. I am only interested in learning to fly as a private pilot. Is it necessary that I should learn all this technical stuff as well?"

Suppose I answer that by asking you a question in turn. Is your own life not every bit as precious to you as the lives of its passengers are to an airline company?

An airplane moves in a medium known as the atmosphere. This layer of air surrounding the earth for a depth of several miles is a turbulent region of shifting winds, cross currents, storms, gusts and squalls. Invisible giants, the Polar and Equatorial Air Masses, forever in conflict, make this atmosphere of ours a perpetual proving ground for the science of air navigation — by frequent blanketing of entire areas with dense drop-curtains of cloud, fog, rain, or snow.

An airplane moves in three-dimensional space, which involves three-fold problems in its control. It lacks buoyancy, is heavier than air, and hence is dependent on the power from its engine to sustain it in flight. A forced landing is not necessarily a hazardous, but under no circumstances a desirable, undertaking. Reliability is therefore a matter of vastly greater importance in the air than on land or sea. And reliability refers not only to the mechanical perfection of the airplane and its engine, but to the knowledge, judgment, and all-round proficiency that rides in the cockpit.

Time was, three wars ago as we measure time nowadays, when an older generation — my own — learned to fly by the seat of its pants. We flew by what is known as "feel". It frequently happened that the ships we flew, being inanimate objects, did not always feel as we felt. The arrangement was a haphazard one and frequently, when we accidentially strayed into a cloud, the only "feel" that most of us had was a feeling of utter confusion.

There was, of course, a certain romance attached to flying in those days. We were gentlemen adventurers pitting our wits against the unknown. The "unknown" is this case included practically everything that had to do with the airplanes, the engines and the conditions under which we flew. A compass, had you asked us, was an affair filled with a precious fluid known as alcohol. Other than that it was a gadget as meaningless as most of the others that littered our instrument panels with misinformation. There was no great point in fussing over mechanical details in those days anyway. The crates we flew were so unreliable they let us down every few hundred miles in any event. It was a hit and miss, happy go lucky era of aviation — but it was not getting anywhere particularly — except to plant a firm conviction in the public mind that flying was the shortest distance between here and the hereafter.

Time marches on, and aviation has since swept ahead with giant strides. Many a private owner today will casually climb aboard his flivver plane to start off on a flight that to the Early Birds would have seemed an epic undertaking. He is equipped with information and knowledge that over six decades of trial and error, of toil and effort and human sacrifice have placed at his disposal. Tomorrow he will blast off into space with equal equanimity.

Those of us, who can count the years we've held a pilot's certificate in multiples of ten, can boast of bearing the scars of many a Near Thing. For we had to get our experience the hard way! Today the Ground School has become an international institution where those, who want to fly the scientifically sure way, may learn the things they should know the only sound and thorough way — FROM THE GROUND UP.

— *SANDY MacDONALD*

The Airplane - - -

The reader may never experience the predicament of being down in the Arctic, 500 miles from the nearest outpost of civilization, with a damaged wing bracing strut or undercarriage. Canada's Northcountry pilots, always noted for their outstanding resourcefulness, have been known, in many such emergencies, to successfully come home on hand whittled propellers, improvised struts and other ingenious make-shift repairs. The average pilot will probably never have occasion, in the course of his career, to rebuild or repair his own airplane, although there is a growing fraternity of aviation enthusiasts these days who are actually building their own airplanes. Whether one of these burgeoning "homebuilders" or simply a pilot who flies a production line model, a fundamental knowledge of the components of the airplane, their functions, structure, and particularly their limitations of strength and resistance to deterioration, is a very essential part of every pilot's qualifications.

THE AIRPLANE

An airplane is defined by the Canadian Air Regulations as a "power-driven heavier-than-air aircraft, deriving its lift in flight from aerodynamic reactions on surfaces that remain fixed under given conditions of flight". There are numerous ways to classify a fixed wing airplane: by the position of its wings in relation to the fuselage, by the number of engines and by its undercarriage configuration. Airplanes may be of the high wing or low wing type. An airplane may be classed as single engine, if it has only one engine, or multi-engine, if it has two or more engines. An airplane is also classified according to the type of landing gear with which it is fitted for this determines the terrain from which it can operate: e.g. land, sea, ski. Landplanes can be further classified as having either conventional or retractable landing gear.

PARTS OF AN AIRPLANE

The essential components of an airplane are:

1. The fuselage or body
2. The wings or lifting surfaces
3. The tail section, or empennage
4. The propulsion system, i.e. engine(s) with or without propeller(s)
5. Undercarriage or landing gear

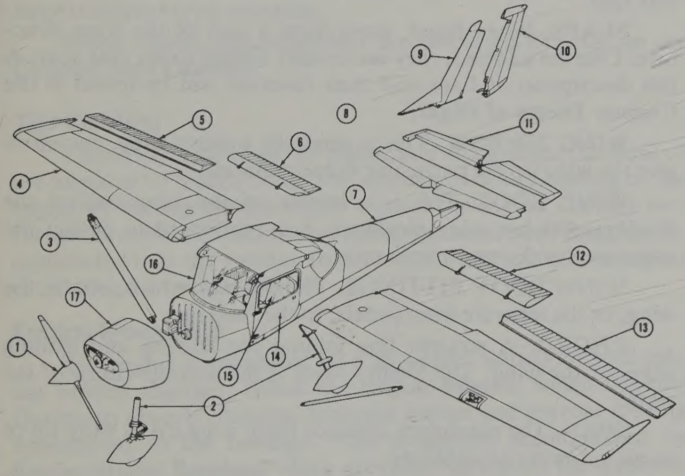


Fig. 1. Parts of an Airplane.

1. Propeller
2. Landing Gear
3. Wing Strut
4. Wing
5. Right Wing Aileron
6. Right Wing Flap
7. Fuselage
8. Horizontal Stabilizer
9. Fin
10. Rudder
11. Elevator
12. Left Wing Flap
13. Left Wing Aileron
14. Door
15. Seat
16. Windshield
17. Engine Cowl

The **airframe** is the term used to describe the complete structure of an airplane, including the fuel tanks and lines, but without instruments and engine installed. It therefore includes the fuselage, wings, tail assembly and undercarriage.

THE FUSELAGE

The fuselage is the central body of the airplane, designed to accommodate the crew, passengers and cargo. It is the structural body to which the wings, tail assembly, landing gear and engine are attached.

The fuselage is usually classed according to its type of construction.

Truss Type

In the early days, the fuselage was a frame made up of wooden members, wire braced. These materials are now obsolete, having been replaced by metal. The modern truss type fuselage is made up of steel tubes, usually welded or bolted together to form the frame. The **Longerons** (three, four or more long tubes running lengthways) are the principle members and are braced, or held together, to form the frame by vertical or diagonal members, the whole assembly being in the form of a truss. Fig. 2 illustrates two types of steel tube truss type fuselage construction: N-Girder, and Warren Truss. The covering may be fabric or metal.

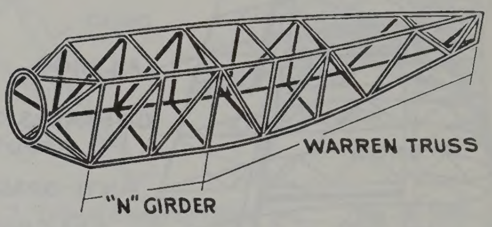


Fig. 2. Truss Type Fuselage.

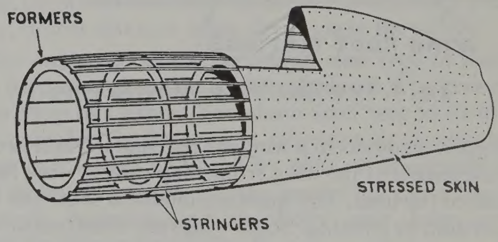


Fig. 3. Monocoque (Stressed Skin) Fuselage.

Monocoque

This type consists of a series of round or oval **Formers** or **Bulkheads** held together by **Stringers** (long strips running lengthwise). The formers, or bulkheads, carry the loads, the stringers being merely superstructure. The early types of Monocoque construction were of wood, plywood covered. Present Monocoque construction is of metal, metal covered. Since the covering of the Monocoque fuselage must be made stiff, the skin is capable of carrying some of the load. This is known as a Stressed Skin structure. A perfect Stressed Skin structure would be one in which the skin, in addition to providing the covering and forming the shape, would be capable of carrying **all** the load, without any internal bracing.

THE WING

Most airplanes in use in general aviation today are monoplanes; that is, they have one wing. Biplanes, those with two wings, are also to be found. They are usually restored antiques, agricultural spray planes, or sport and aerobatic airplanes. Wings come in a variety of shapes: rectangular, tapered from wing root to wing tip, elliptical, delta. They may be attached in different positions on the fuselage: at the top of the fuselage, known as high wing; at the bottom of the fuselage, low wing; or in the middle, mid wing. High wing airplanes may be externally braced with wing struts or may be fully cantilevered.

Five general systems of wing construction are now in use on modern airplanes. These are:

1. Metal frame, metal covered (main strength in the covering, or skin, i.e. **Stressed Skin**).
2. Metal frame, metal covered (main strength in the frame).
3. Metal frame, fabric covered.
4. Wooden frame, fabric covered.
5. Wooden frame, plywood covered.

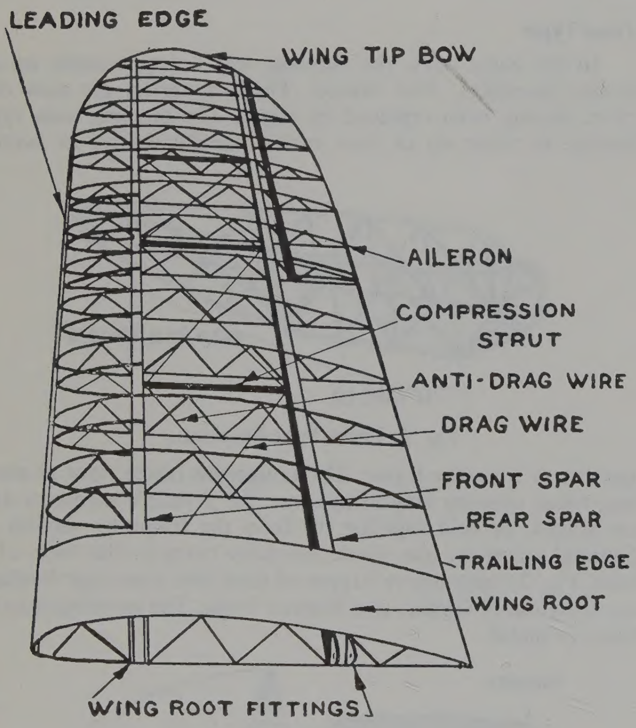


Fig. 4. Two-Spar, Fabric-covered Wing.

The main members in a wing are the **Spars.** These are beams, running the length of the wing from wing root to wing tip, which carry most of the load. The spars are intended to stiffen the wing against torsion, or twisting. Some wings are constructed with two or more spars **(multispar)** and some with only one main spar **(monospar).** The latter type of single spar construction is found in certain models of modern airplanes which use a laminar flow airfoil wing design.

The **Ribs** run from the leading to the trailing edge. They are cambered to form an airfoil section and their purpose is to give the wing its shape and to provide a framework to which the covering is fastened. To strengthen the leading edge, nose ribs are sometimes installed between the front spar and leading edge. These are generally known as **False Ribs.**

Compression struts are spaced at regular intervals between the front and rear spars. They are usually steel tubes and are intended to take compression loads.

Further internal bracing is secured by **Drag** and **Anti-Drag Wires.** These are wires running diagonally from the front to the rear spars, the drag wires taking drag loads and the antidrag wires antidrag loads, as their names imply.

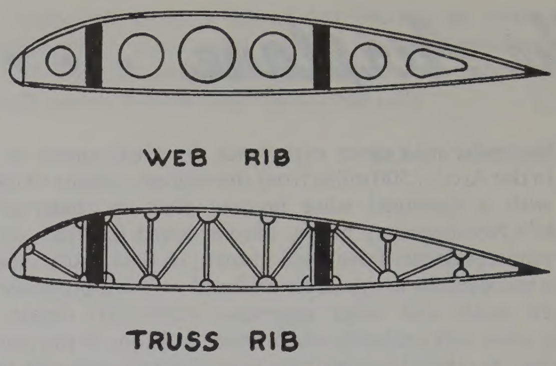


Fig. 5. Ribs.

External Bracing is secured in monoplane types by **Wing Bracing Struts** which extend out from the fuselage to about the mid-section of the wing. In biplanes, **Struts** are placed between the wings, well out towards the tips. These are braced by **Incidence Wires** which run diagonally between the struts, and by **Flying** and **Landing Wires** which run diagonally between the struts and the fuselage. The flying wires transmit part of the load to the fuselage in flight and the landing wires support the weight of the wing on the ground.

Some wings are constructed with no external bracing at all. These are known as **cantilever** wings. Since there is no external support to such a wing, the spars must be made sufficiently strong to carry the load into the fuselage internally with no outside assistance.

Transmission of Loads — Internally. The load on a wing comes first on the skin. It is then transmitted to the ribs and from these to the spars and thence carried into the fuselage.

Externally. In an externally braced wing, part of the load is taken by the bracing struts or the flying or landing wires, as the case may be, and thence transmitted to the fuselage.

AILERONS. These are surfaces, usually of airfoil section, hinged to the trailing edge of the wing towards each wing tip for the purpose of **lateral control.** Their internal construction is much like that of the wing itself. They are usually hinged to the rear spar.

FLAPS. When fitted, these form a part of the wing structure. Like the ailerons, they are usually hinged to the rear spar. A full description of flaps and their function will be found in the Chapter **Theory of Flight.**

WING TIP BOW. This is generally a metal tube, curved to give the wing tip the particular shape required.

WING ROOT. This is a section of the wing nearest the fuselage. On low wing airplanes, it is reinforced to permit the passengers and crew to walk on it.

WING ROOT FITTINGS. The fittings which attach the wing, or the separate wing panels, to the fuselage.

CHORD. A straight line joining the leading and trailing edges of the wing. The Mean Chord is the average chord of the wing.

SPAN. The maximum distance from wing tip to wing tip of an airfoil, wing or stabilizer.

THE TAIL SECTION OR EMPENNAGE

The empennage is the tail section of the airplane and consists of a fixed vertical stabilizer or fin, the rudder, the stabilizer or tail plane, the elevators and all trimming and control devices associated with them. Instead of a fixed stabilizer and movable elevators, some airplanes have a one piece pivoting, horizontal stabilizer that is known as a stabilator.

THE TAIL PLANE or STABILIZER. An airfoil placed at the rear end of the fuselage to balance the airplane and hence provide **longitudinal stability.**

ELEVATORS. Surfaces hinged on the trailing edge of the stabilizer to give **longitudinal control.**

FIN. A fixed vertical surface placed ahead of the stern post to provide **directional stability.** The fin is usually offset from the centre to offset the slipstream from the propeller.

RUDDER. A moveable surface hinged to the fin to give **directional control.**

STABILATOR. A single airfoil section that replaces the combination of stabilizer and elevator. It is attached to the fuselage at a point around which it pivots.

The airfoils comprising the tail unit assembly are similar to, but of lighter construction than those of the main structure. The tail unit is positioned so that it is in the airflow and not blanketed by the main planes or other parts of the structure.

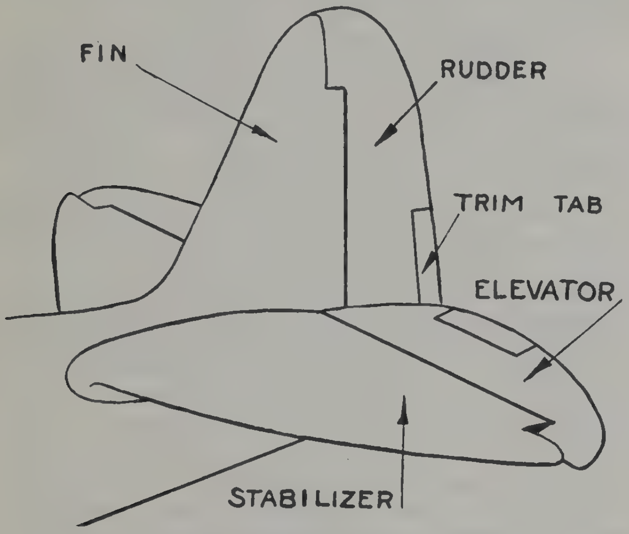


Fig. 6. The Tail Section.

THE PROPULSION SYSTEM

The propulsion system of the modern general aviation airplane is generally a gasoline powered, air cooled, internal combustion engine, that drives a 2 or 3 bladed propeller. Many of the new business airplanes are jet powered as are most of the large transport type airplanes.

Power plants and propellers are discussed in detail in the Chapter **Aero Engines.**

The Cowling

The cowling encloses the engine and streamlines the front of the airplane to reduce drag. The cowling provides cooling of the engine by ducting the cooling air around the engine. On high performance airplanes, adjustable openings called **cowl flaps** are incorporated into the cowling to control the amount of cooling air circulating around the engine.

Engine Mountings

The engine is supported by a structure, usually of steel tubing welded together, called the **Engine Mount,** which is made flexible to absorb vibration from the engine and prevent it being transmitted to the fuselage. This is usually accomplished by **Engine Mount Bushings** which are made springy in the direction of the engine rotation but rigid otherwise, in order to hold the engine steady fore and aft.

Fire Wall

Between the main structure and the engine is the **Firewall.** This is made of a heavy sheet of stainless steel or often a sandwich of asbestos between two sheets of dural. Openings for fuel and control lines are made small, with bushings to insure a snug fit. The fuel tank must be behind the fire wall, whereas the oil tank may be ahead of it—oil being less inflammable than gasoline.

Tank Installations

Fuel tanks may be carried in the wings or in the fuselage. See **Fuel System** in Chapter **Aero Engines.**

LANDING GEAR OR UNDERCARRIAGE

The function of the landing gear is to take the shock of landing and also to support the weight of the airplane and enable it to maneuver on the ground. The earliest type of main landing gear was a through axle, similar to the wheel and axle arrangement on a cart or wagon. This is now completely obsolete, having been replaced with more sophisicated, shock absorbing landing gear systems.

The landing gear on modern airplanes is either of the fixed gear type or retractable.

Fixed Undercarriage

On land airplanes, there are two basic classes of fixed gear undercarriage: conventional gear with a tail wheel, and tricycle gear, with a nose wheel. There are several types of undercarriage in use for the main gear. These are used with both the conventional and tricycle configuration. They are **split axle, tripod, single spring leaf cantilever** and **single strut.**

The **split axle** type has the axle bent upwards and split in the centre to enable it to clear obstructions on the ground (Fig.8). This type is used on airplanes such as the Piper PA-22. It is suspended on shock cords wound around a fuselage member which enables the whole assembly to spread when the loads come on it. A strut or tie rod is usually incorporated to brace the structure against side loads.

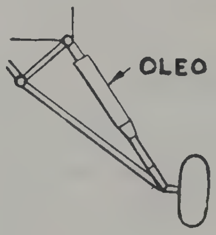


Fig. 7. Tripod Landing Gear.

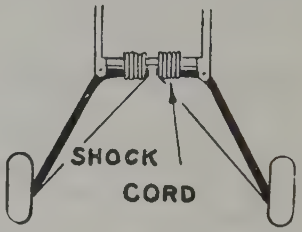


Fig. 8. Split Axle.

The **tripod** landing gear is illustrated in Fig. 7 and is typical of airplanes such as the Aeronca and the Champion. This gear consists of three members hinged so as to form a triangle. Two of these are rigid. The third is an oleo leg, designed to telescope and hence shorten its length when the load comes on the wheel. On landing, the whole assembly spreads outwards and upwards until springs, rubber disks, or other devices take the weight.

The **single leaf cantilever spring steel** type of main landing gear is used extensively on Cessna airplanes. The gear consists of a single strap of Chrome Vanadium Steel bent to form the shape of the complete undercarriage structure. It is attached to the fuselage in a cradle bulkhead by bolts. It is capable of storing energy in initial impact, thereby producing quite low load factors. Low maintenance, simplicity and long service life characterize this gear type (Fig.9).

On the Cessna "Cardinal", a spring steel tubular gear replaces the more familiar single leaf gear described here. The

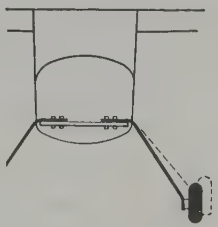


Fig. 9. Single Leaf Cantilever Spring Steel Gear.

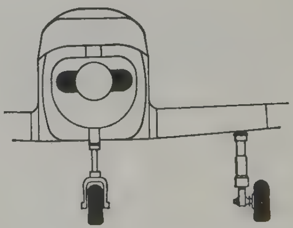


Fig. 10. Single Strut Gear.

spring steel tubular gear has the same characteristics as the single leaf type.

The **single strut** type is used on several modern, low wing, fixed gear airplanes such as the Piper Cherokee, the Beech Musketeer. This gear consists of a single leg or strut extending downward from its attachment point on the main spar. The strut usually incorporates a hydraulic cylinder or rubber biscuits for the purpose of absorbing the shock (Fig.10).

Retractable Gear

Retractable gears are made to retract or fold up into the wing or fuselage in flight. The mechanical means and methods for accomplishing this are many and varied. The wheel may fold sideways outwards towards the wing or inwards towards the fuselage. The latter is most common on high speed military airplanes when the wing camber is shallow. On some multi-engine airplanes the wheel folds straight back or forward into the nacelle and is left partly projecting in order to protect the belly of the ship in the case of a wheels-up landing. Some retractable undercarriages are made to turn through 90° as they travel up and so fold into the side of the fuselage.

Most retractable undercarriage legs are cantilever, being a single oleo leg with no external bracing. They are hinged at the top to permit them to fold. The means of retraction may be a hand gear, electric motor, or motor-driven hydraulic pump. Where mechanical means are used, a hand gear is also provided for lowering in an emergency.

Both conventional gear and tricycle gear are common in the retractable gear configuration.

Tricycle Versus Conventional Landing Gear

The practice of placing a steerable third wheel forward of the main gear has found universal acceptance in modern airplane design and is referred to as being a tricycle gear arrangement. The landing gear arrangement in which the third wheel is rearward of the main gear (i.e., at the stern of the airplane) is referred to as a tail wheel or conventional arrangement. The recent trend to tricycle gear arrangement by most manufacturers is the result of certain advantages that this type of landing gear has over the conventional tail wheel arrangement. These advantages are: (1) Nose-over tendencies are reduced greatly. (2) Ground looping tendencies are reduced. (3) Visibility over the nose when taxiing, taking off or landing is superior due to the level flight position of the airplane while on the ground. (4) Greater maneuverability on the ground under high wind conditions due to the negative angle of attack of the wings. (5) Greater controllability on the ground in cross wind conditions. Therefore, tricycle geared airplanes can use single runway airports (which are becoming more numerous) with greater safety in cross wind conditions than can conventional geared airplanes. (6) A novice can usually learn to maneuver a tricycle geared airplane on the ground in less time than he can a conventional geared airplane.

Tail wheel airplanes have advantages too. These are: (1) The tail wheel has less parasite drag than a nose wheel due to its smaller size. (2) The tail wheel is cheaper and easier to build and maintain. (3) A broken tail wheel will not result in as much damage to an airplane as would a broken nose gear. (4) A tail wheel airplane can be more easily man handled on the ground and, because the tail is lower than that of a tricycle-geared airplane, it fits into some hangar space more easily. (5) When using rough sod, sand or gravel airports, the tail wheel airplane will sustain less propeller damage since the tips of the propeller are farther away from the ground and are less likely to pick up loose objects, such as stones and debris. (6) With constant use in rough fields, the conventional geared airplane is not as likely to sustain airframe damage since it is the main undercarriage which takes the bulk of the load and the shock when the airplane rides over depressions and irregularities on the ground. The main undercarriage (which hits the "bumps" first) is attached to a primary structure and is therefore stronger and more rigid than a nose gear (which in the tricycle gear arrangement is the first to hit the "bump") which is usually fastened to a weaker or non- primary part of the airframe. A tail wheel will easily absorb bumps that may be severe enough to damage a nose gear. (7) Tail wheel airplanes are more suitable for change-over to ski operations in winter.

On most modern airplanes, regardless of whether they have a fixed or retractable undercarriage, the nose wheel in the case of tricycle gear or the tail wheel in the case of conventional gear is steerable by the pilot's controls.

Shock Absorbers

The purpose of the shock absorber is to prevent landing shock damage to the fuselage or body of the airplane. Pilots may accidentally impose heavy stresses due to faulty landings. If these stresses were not properly absorbed by landing gear they could easily cause failure in the airplane structure.

Shock absorbers generally are divided into four classes:

1. **Low Pressure Tires:** On some types of light airplanes these are the sole means provided for absorbing shocks. The principal difficulty with tires (and some of the other shock absorbing devices) is that they do not dissipate the shock but **store** it and kick the airplane back into the air after a rough landing.

2. **Oleo:** When the airplane hits the ground the momentum must be absorbed in the undercarriage. To absorb this energy on springs or rubber alone would result in the aircraft being bounced into the air again. On practically all modern airplanes, the energy produced on landing is dissipated by forcing oil (an incompressible fluid) from one side of a piston to the other through a **small orifice.** The displacement of the oil is thus **delayed,** cushioning the shock of landing for the reason that the bulk of the energy is absorbed in forcing the oil through the restricted orifice.

The simple oleo (Fig. 11) consists of an **Inner Cylinder** which is attached to the fuselage and an **Outer Cylinder** fastened to the wheel. On landing, these will telescope, and the oil will be displaced from the lower to the upper, but is delayed in doing so by the restricted orifice. Since the oil, once displaced, will not return until the airplane again leaves the ground, the oleo leg serves **only to absorb the shock of landing.** Further shocks experienced while taxiing or taking off are handled by devices such as the spring shown in Fig. 12 (Oleo-Aerol), or by compressed air, Fig.13 (Oleo-Pneumatic).

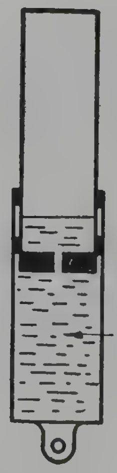


Fig. 11.
Simple Oleo.

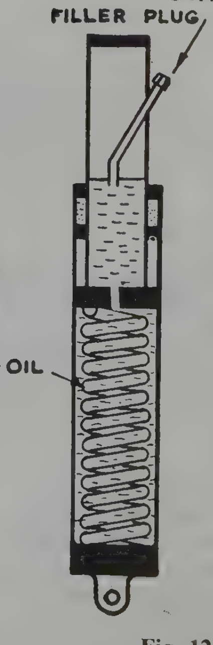


Fig. 12.
Oleo-Aerol.

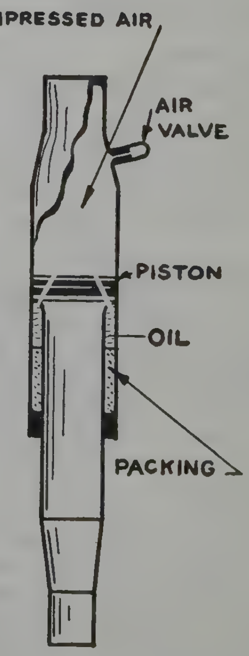


Fig. 13.
Oleo-Pneumatic.

3. **Rubber:** Two types of rubber shock absorbers are in use, usually in conjunction with the oleo, to cushion further shocks after landing. These take the form of rubber **Discs** or **Doughnuts,** and **Shock Cord,** which is an elastic cord wound around two moving members .

4. **Spring Steel:** The spring steel type of landing gear, as described above, is in itself a shock absorber capable of storing energy.

Brakes

The advantage of the use of brakes on airplanes is two-fold:

1. They provide quick deceleration, or pull-up, after landing. For heavy and high speed airplanes that land with faster initial, or "hotter", speeds, such quick deceleration is important, especially when landing on short runways.

2. Differential, or individually operated brakes, ensure better control after landing, to prevent "ground loops", etc. They also provide better maneuverability on the ground.

Due to the much higher landing speeds of modern airplanes, brakes have to be powerful, reliable and capable of dissipating heat very rapidly.

Nearly all airplanes use **Disc Brakes** operated by hydraulic pressure, sandwiching a rotating **Disc** between two brake linings called **Pucks.**

These pucks are located in a fixed cast unit, grooved to permit the disc to float freely. Attachment of the disc is attained by splitting the periphery into the wheel hub. This floating action allows the disc to move laterally during braking and permits the use of one moving puck. The fixed puck is called the **Anvil**; the moving one is called the **Piston Puck.**

Upon applying pressure the piston puck moves the disc against the anvil puck, attaining equal braking force on both sides of the disc. Special **Flexible Sealing Rings** keep the puck-to-disc clearance automatically adjusted by returning the **Hydraulic Piston** to a neutral position after each braking action.

Disc brakes are so reliable that, normally, visual inspection is required only at 50 hour intervals. One precaution in their use is recommended. The parking brake should be left off and wheel shocks installed if the airplane is to be left unattended. Changes in the ambient temperature can cause the brakes to release or to exert excessive pressure.

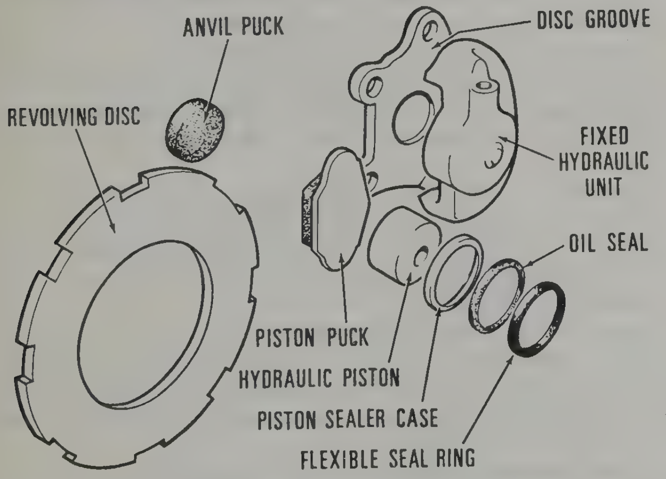


Fig. 14. Hydraulic Brake.

The Principle of the Dunlop Pneumatic Brake is somewhat like the idea of placing an automobile tire on the *inside* of the brake assembly. Air pressure admitted to this tire, or **Pressure Bag,** causes it to expand, forcing the **Brake Shoes** to move radially outward against the surface of the **Brake Drum.**

THE CONTROL SYSTEMS

AILERONS

The ailerons are control surfaces attached to the trailing edge of the wing near the wing tip and are employed to bank the airplane. They move in opposite directions to each other and are controlled by movement of the control wheel or stick.

Three types of control systems may be used to operate the ailerons. These are: 1. cables and pulleys, 2. push and pull rods and 3. torque tubes (Fig. 15). When stick control is used, any of these systems may be employed. With wheel control, cables and pulleys are generally used, but push and pull rods may be.

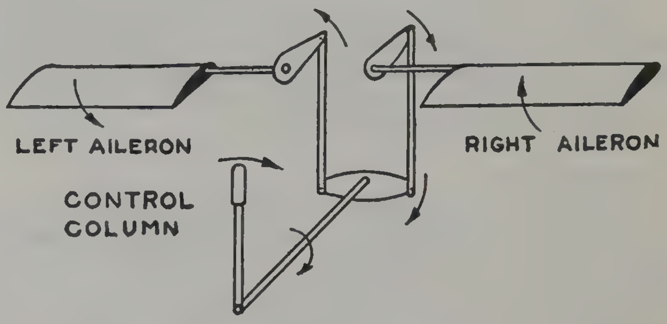


Fig. 15. Torque Tube Aileron Control.

When the control wheel is rotated to the right (or the control column moved to the right), the left aileron moves down and the right aileron moves up. The lifting capability of the left wing is therefore increased at the same time as the lifting capability of the right wing is decreased. The left wing lifts and the right wing descends and the airplane rolls to the right. The airplane will continue to roll to the right, steepening the angle of bank, until the controls are neutralized establishing a particular angle of bank.

ELEVATORS AND STABILATORS

A movable tail surface controls the movement of the airplane longitudinally and controls the angle of attack of the wings. The movable tail surface may be either elevators or stabilators.

The elevators or stabilators are attached to the control wheel by: 1. a system of cables and pulleys, 2. a rocking beam and cable, or 3. a push and pull rod system. These systems are equally effective with either a control wheel or stick configuration.

The elevators are hinged to the trailing edge of the horizontal stabilizer and are controlled by forward or aft movements of the control wheel. They move together. When the control wheel is pushed forward, the elevators move down, increasing the lifting capability of the tail. The tail rises and the nose of the airplane moves down. When the control wheel is pulled back, the elevators move up, the lift on the tail is decreased, the tail moves down and the nose of the airplane rises.

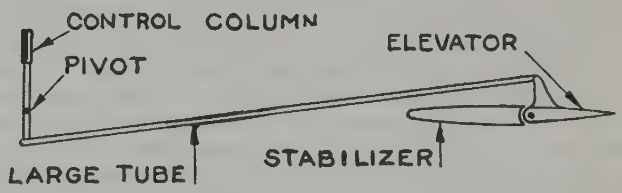


Fig. 16. Push and Pull Rod Elevator Control.

The stabilator is a one piece, horizontal tail surface that pivots up and down. It operates on the same principle as the elevators, moving up or down, changing its angle of attack and hence its lifting capabilities as the pilot pulls back or pushes forward on the control wheel.

RUDDER

The rudder moves the airplane either left or right in a motion known as yaw. The rudder is attached to the trailing edge of the vertical stabilizer, or fin, and is connected to the rudder pedals by a cable system.

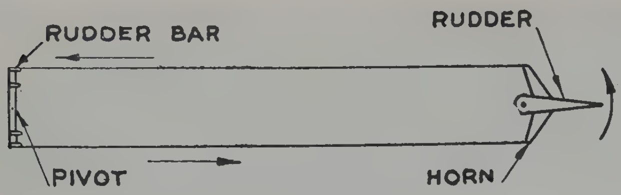


Fig. 17. Cable Rudder Control.

Pressure applied to the left rudder pedal displaces the rudder to the left into the airstream, increasing the pressure on the left side of the tail and forcing the tail to move to the right. The nose of the airplane moves to the left. The rudder is used with the ailerons to achieve co-ordinated turns.

TRIM SYSTEMS

To minimize the pressure on the various control surfaces, several types of trim devices are incorporated into the control system.

Trim Tabs

Trim tabs are adjustable devices located at the trailing edge of control surfaces such as elevators, rudders or ailerons. Their function is to permit the pilot to fly the airplane in a desired attitude, under various load and airspeed conditions, without the need to apply constant pressure in any particular direction on the flight controls.

A trim tab is, in effect, a control surface hinged to another control surface. It is designed to move above or below the chord line of the control surface to which it is attached and thereby create an aerodynamic force that assists the pilot in holding the control in the desired position. The trim tab, for example, is deflected downward in order to hold the control surface up. (See Fig. 18, in which a nose up attitude is achieved by use of trim tabs.)

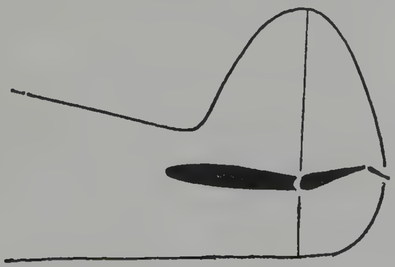


Fig. 18. Elevator Trim Tab.

The trim tab is operated from the cockpit by its own control which is located to be within easy reach of the pilot. A tab position indicator is incorporated in the control mechanism to show the nose up or nose down position of the tab setting. The mechanism that operates the trim tab is usually a system of wires and pulleys.

The trim tab is not the only device for affecting trim. Some trimming devices incorporate an adjustable spring tension as a means to exert pressure on the control surface to maintain the "trimmed" position. These are known as **bungees.**

Some form of inflight adjustable trim control is incorporated into the pitching plane of even the smallest airplane. Trim controls are also used on aileron controls, especially on multi-engine airplanes, and on rudder controls.

On airplanes, in which in-flight adjustable trim is incorporated only on the elevator controls, ground adjustable trim tabs are often attached to ailerons or rudder. These have the effect of helping to correct any slight tendency of the airplane to roll or yaw as the result of less than perfect rigging.

Anti-servo tabs serve as trimming devices on stabilators.

Servo tabs are a device found most often on larger airplanes. They are connected directly to the control column. As in the case of the elevator, if the pilot moves the control column back, the servo tab is deflected downward. Air pressure on the tab deflects the elevator control upward to achieve a nose up attitude. The control column controls the servo tab, the elevator is free floating and moves in accordance with the tab deflection.

Adjustable Stabilizer

On some airplanes, longitudinal trim is achieved by adjusting the angle at which the stabilizer is attached to the fuselage. The leading edge of the stabilizer is moved up or down by means of a screw jack device that is controlled by a wheel or crank in the cabin. To effect a nose down attitude of the airplane, the leading edge of the stabilizer is rotated up, giving the stabilizer a higher angle of attack. The stabilizer, like trim tabs, can be set in any position between full up and full down. The adjustable stabilizer has the advantage of producing less drag than the conventional trim tab.

Movable Tail

On some airplanes, the entire empennage is hinged to pivot either forward or aft. A nose down attitude is achieved by rotating the tail aft. A nose up attitude results from rotating the tail forward.

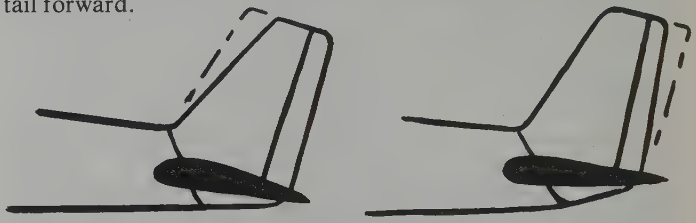


Fig. 19. Movable Tail.

CONSTRUCTION MATERIALS

STEEL: Low Carbon Steels are tough, ductile and readily weldable but are incapable of being surface hardened except by case hardening.

Mild Steels can be hardened, are strong but less ductile, less weldable. Used for fuselages and control surfaces.

High Carbon Steels exhibit increased strength and hardness but at the sacrifice of ductility and weldability.

Alloy Steels, such as Chrome Moly, are very strong and resistant to impact and vibration. Used in the fabrication of fuselages. Alloy Steels containing Nickel (called Stainless Steel) are very corrosion resistant. Used for stressed skin structures, particularly in seaplane construction.

DURAL: An aluminum wrought alloy containing copper and magnesium. Has a very high tensile strength and fatigue endurance. Susceptible to corrosion but can be treated by anodizing. Used for ribs, tanks, bulkheads, propeller blades, fittings, etc., etc.

ALCLAD: A sandwich of dural between two layers of pure aluminum (the aluminum layers constituting about 5-1/2% of the whole). The aluminum protects the Dural and prevents corrosion. Very corrosion resistant. Used in seaplane construction. Needs no anodizing.

MAGNESIUM ALLOY: An alloy in which magnesium forms the principal constituent. Combines tensile strength with light weight (one-third lighter than aluminum). Used extensively in aircraft engine construction. Very corrodible in sea water, and should always be anodized.

HONEYCOMB SANDWICH CONSTRUCTION: A metal honeycomb pattern between sheets of metal (Fig. 20). For cabin floor, door surfaces, etc., it offers the advantage of high strength/weight ratio, a smooth surface that does not

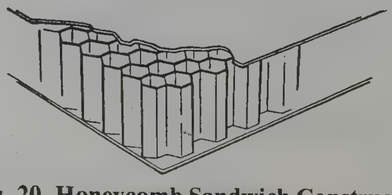


Fig. 20. Honeycomb Sandwich Construction.

buckle under load, and excellent bearing and bending properties in all directions. In supersonic airplanes, its ability to dissipate high temperatures makes it particularly suitable for wing skin structures.

COMPOSITE: Fibreglass cloth and epoxy resin moulded over a foam form constitute the airplane structure.

WOOD: Wood is still used in airplane construction for structural members. Plywood is used as a covering, giving a very smooth finish. Some airplanes are all wood; others are partly wood.

FABRIC: Airplanes whose fuselage structures are made of steel tubing may be covered with cotton, linen or synthetic fabric. The fabric is drawn taut either by the use of aircraft dope (cotton or linen) or by shrinking with a hot iron (synthetics such as Dacron). Fabric is also used as the covering of wings whose spars and ribs are either all wood or all metal or a combination of both.

CORROSION

Corrosion must be treated as the enemy of all metal parts of an airplane. Generally speaking, corrosion is of two types:

1. **Oxidation:** This is produced by atmospheric conditions due to the moisture in the air. The effect is worse in the vicinity of salt water. The action consists of the dissolving of the surface by oxidation. Such oxidation is easy to detect. It may be removed and the surface treated with some preventative so further damage will not occur.

2. **Intercrystalline:** This type is more serious. It is caused by chemical or electrolytic action between the alloys in the metal itself. It may not become visible until considerable damage has been done. Surface protection aids very little in the prevention of this type of corrosion. The affected parts must be removed and replaced.

Another form of corrosion occurs as a result of two different kinds of metal being placed in contact without first being treated by the process known as **Cadmium Plating** or **Metalizing.**

STRESSES

A STRESS is the force, or combination of forces, exerting a strain. A pressure of your hand on the surface of, say, an empty cigarette box is a stress.

A STRAIN is the distortion in form or bulk of a body due to stress. If the cigarette box is crushed, it is said to be **strained.** A wire stretched is another example of **strain.**

There are five distinct types of stress:

1. COMPRESSION— or "crushing", as in the case of the cigarette box. Airplane wings are subjected to compression stresses.

2. TENSION—or "stretching", as in the case of the wire. Bracing wires in airplanes are usually in tension.

3. TORSION—or "twisting". A screwdriver is subjected to severe torsional stress when forcing a screw into hard wood. Landing gear must be made to withstand torsional stresses.

4. SHEARING—or "cutting". The blades of scissors exert a shear stress on a piece of paper, which is "sheared" as a result.

5. BENDING—as the name implies, means the bending of a long member due to a load or weight being imposed on it. Aircraft spars, or beams, must resist severe bending stresses.

An airplane structure in flight is subjected to many stresses due to the varying loads that may be imposed. The designer's problem is to try to anticipate the possible stresses that the structure will have to endure, and to build it sufficiently strong to withstand these. This problem is complicated by the fact that an airplane structure must be **light** as well as **strong.**

Strength and lightness are essential in the structure of an airplane. Another factor almost as essential as strength is **Rigidity.** Excessive deflection or bending under a load may lead to a loss of control with serious consequences.

Lack of rigidity may also lead to **Flutter.** This is a rolling or weaving motion which arises when a deflection of a part of the structure causes the air forces on it to change in synchronism with its natural period of vibration. Flutter is most likely to occur in wings and control surfaces and may lead to structural failure. To prevent flutter, the wing and tail structures must be made stiff against both bending and twisting.

The narrow margin of safety permitted by weight limitations in airplanes makes it necessary that every member must bear its proper share of the load in every condition of flight. To attain uniform and adequate structural safety it is essential to calculate what load each part may be called upon to carry. Such a determination of loads is called a **Stress Analysis.** This is a complicated mathematical process, and is distinctly a job for only the trained engineer.

LOADS AND LOAD FACTORS

Airplane strength is measured by the total load the wings are capable of carrying. The load imposed on the wings depends on the type of flight. The wings must support not only the weight of the airplane but also additional loads imposed during maneuvres.

The WING LOADING of an airplane is the **Gross Weight** of the airplane divided by the **Area** of the lifting surfaces and is expressed in lb. per sq. ft., i.e. the number of lb. that each sq. ft. of lifting surface must support.

The SPAN LOADING of an airplane is the gross weight divided by the span and is expressed in lb. per foot.

The POWER LOADING is the gross weight of the airplane divided by the hp of the engine(s) and is expressed in lb. per hp.

LOAD FACTOR: The weight of an airplane standing on the ground (or its weight due to gravity alone) is commonly referred to as a **Dead Load.** In flight, however, the weight of an airplane may be increased many times by **Acceleration** (rate of change of speed) and/or by a change of direction. The additional loading imposed is called a **Live Load.**

The **Load Factor** is the ratio of the actual load acting on the wings to the Gross Weight of the airplane. In other words, it is the ratio of the Live Load to the Dead Load. When an airplane is in level flight, the lift of the wings is exactly equal to the weight of the airplane. The load factor is then said to be 1. In most maneuvres, such as a change in attitude, a banked turn, a pull out or any maneuvre causing acceleration, centrifugal force enters the picture and brings about a change in the load factor. In a level turn at a bank angle of 30 degrees, for example, the load on the wings is increased to 1.15. In a 60 degree bank, the load factor goes up to 2. In a hard landing, the total load acting upward on the wheels may be as much as 3 times the weight of the airplane. The **Landing Load Factor** in this case would be 3.

A load factor of 3 is often expressed as 3g. "g" in this case refers to "gravity". Hence, 3g's means a load on the wings equal to three times the weight of the airplane due to gravity alone.

An airplane designed for a load factor of 6 means that the wings are designed to take a load up to six times the weight of the airplane. This means that the wing will break at a load factor of 6, which is therefore called the **Ultimate Load Factor.** The load factor at which a permanent set or distortion of the structure begins to take place is called the **Yield Load Factor.** This is usually about two-thirds of the Ultimate Load Factor.

The flight maneuvers which impose high load factors are: steep turns, pull-outs, flick rolls, tail slides, and inverted loops. **These should be executed with due consideration on the pilot's part of the stresses which the particular airplane he is flying is designed to withstand.**

Airplanes which fly at several times their stalling speed are subject to excessive g-loads in some circumstances. In an airplane that is flying at twice its stall speed, if the angle of attack is abruptly increased to obtain maximum lift, a load factor of four will be produced; at three times the stall speed, nine g's would result; at four times the stall speed, sixteen g's would result.

Weight also imposes high load factors. If an airplane is heavily loaded, the allowable load factors will be reduced accordingly and the pilot is likely to damage the structure in maneuvers that would normally be quite safe. **Therefore when doing aerobatics always be sure that the airplane is lightly loaded.**

In flying a heavily loaded airplane, a pilot should not trust his senses in determining the actual load on the wings. Because the heavy airplane is steady even in rough air, the pilot may get the false impression that the air turbulence is not excessive. However, the wings sense the actual "load" and may be about at their breaking point. On the other hand, a pilot flying an airplane that is lightly loaded may experience a good deal of buffeting and personal discomfort in rough air. Because of this, he may feel that the "load factor" is excessive whereas the wings which sense the actual "load" are not being over stressed.

Gust Load. Gusts are rapid and irregular fluctuations of varying intensity in the upward and downward movement of air currents. An airplane in a rising or descending current of air is not affected. When, however, the speed or direction of the air current changes abruptly—such as when flying at high speed through successive up-and-down gusts—load changes are imposed on the airplane structure. When an airplane flies out of a down-gust, and immediately into an up-gust, for example, the effect on the wings is to suddenly increase the angle of attack. The **lift** is then in excess of the weight, and the airplane accelerates in an upward direction—just as it would if the pilot suddenly pulled back on the controls. If the total lift were to exceed the total weight by a factor of 2, the airplane would experience a 2g acceleration. This is known as a **Gust Load.**

Gusts, therefore, can impose very high load factors on the airplane. For this reason, when flying in rough air conditions, the speed of the airplane should be somewhat reduced below the normal smooth air cruising speed. Airplane manufacturers always specify in the Aircraft Owners' Manual a recommended **Maneuvering Speed** for each model of airplane. This is the maximum speed at which abrupt control travel can be used without exceeding the design load factor and damaging the airplane structure while allowing a sufficient margin of safety above the stalling speed in gusty air.

Gust Loads can be sufficiently severe to be dangerous. Extremely rough air should be avoided. In moderately rough air, as stated above, speed should be reduced to the recommended Maneuvering Speed. Since there is a risk of stalling the airplane in rough air, the speed should not be reduced below this recommended airspeed.

These facts relating to loads are of critical importance and should be understood and intelligently applied so that you never impose loads on any airplane that you might be flying in excess of the limit load for which it was designed.

LOG BOOKS

The life of the airframe, engine(s) and propeller(s) is recorded in the Aircraft Technical Log which comprises an Airframe Log, a record of Installations and Modifications, an Engine Log for each engine and a Propeller Log for each propeller. All maintenance, repairs, new installations, modifications, etc., must be completely recorded in the appropriate section of the Aircraft Technical Log.

A complete record of all flying time and particulars of every flight is kept in a suitable Aircraft Journey Log.

Regulations governing the recording of flying and maintenance data will be found in Air Regs Part VIII, 821-5, the Flight Information Manual and in ANO Series VIII, No. 2 and 3.

INSPECTION

An airplane must be inspected by a qualified maintenance engineer and certified as airworthy in the Aircraft Log periodically as specified in Air Regulations and Air Navigation Orders.

Regulations with regard to Inspection are contained in ANO, Series II, No. 4 (Can).

Theory of Flight . . .

Why learn about Theory of Flight?

The pilot today has a large variety of airplanes from which to choose. Some of these airplanes may fly at less than 100 mph top speed while others are capable of speeds well into the hundreds of miles per hour. Some are single seaters carrying only the pilot, while others, even in the single engine light airplane classification, may carry 10 or more passengers. Some airplanes have laminar flow airfoil sections; others have airfoils of conventional design. A few light airplanes fly at 3½ times their stalling speed; others do well to cruise at 1⅓ times their stalling speed. Every one of these airplanes has different flight characteristics. If a pilot has a good grasp of the fundamentals of flight, he will understand what to expect of each different airplane that he may have the opportunity to fly. He will understand how best to handle each airplane as a result of his knowledge of the theory of design. He will comprehend the various loads to which an airplane of a particular design may be exposed while flying under abnormal or adverse conditions of flight. Not only to get the best performance but also to ensure the safety of each flight, an understanding of "Theory of Flight" is essential.

The study of Theory of Flight and Aerodynamics can be a life time proposition. New theories are forever being put forward. Some questions have answers that are difficult to find. Others perhaps do not yet have adequate answers. The information that comprises this chapter can only be considered an "introduction" to a substantial but fascinating study.

FORCES ACTING ON AN AIRPLANE IN FLIGHT

There are four forces acting on an airplane in flight. These are Thrust, Drag, Lift and Weight.

1. THRUST. The force exerted by the engine and its propeller which pushes air backward with the object of causing a reaction, or thrust, in the forward direction.
2. DRAG. The resistance to forward motion directly opposed to Thrust.
3. LIFT. The force upward which sustains the airplane in flight.
4. WEIGHT. The downward force due to gravity, directly opposed to Lift.

When Thrust and Drag are equal and opposite, the airplane is said to be in a state of **Equilibrium.** That is to say, it will continue to move forward at the same uniform rate of speed. (Equilibrium refers to steady motion and not to a state of rest.)

If either of these forces becomes greater than the force opposing it, the state of equilibrium will be lost. If Thrust is greater than Drag, the airplane will **accelerate** or gain speed. If Drag is greater than Thrust, the airplane will **decelerate** or lose speed.

Similarly, when Lift and Weight are equal and opposite, the airplane will be in equilibrium. If Lift, however, is greater than Weight, the airplane will climb. If Weight is greater than Lift, the airplane will sink.

Let us first consider the force of Lift.

LIFT

If you consider the definitions cited by air authorities, a boy flying a kite could be construed to be a pilot in charge of an airplane! Ponder the idea a moment and it may not appear quite as absurd as it seems at first glance.

A kite is an inclined plane, the weight of which is supported in the air by the reaction of the wind flowing against it. If we substitute for the string, which holds the kite against the wind, the engine and propeller of an airplane, which move the wings forward against the airflow, we will see that the analogy of the kite is not without some validity.

The wings of an airplane are so designed that when moved through the air horizontally, the force exerted on them produces a **Reaction** as nearly vertical as possible. It is this reaction that **lifts** the weight of the airplane.

Airfoils

An airfoil, or airfoil section, may be defined as any surface designed to obtain a reaction from the air through which it moves, that is, to obtain **lift.** It has been found that the most suitable shape for producing lift is a **curved** or **cambered** shape.

The **camber** of an airfoil is the curvature of the upper and lower surfaces. Usually the upper surface has a greater camber than the lower.

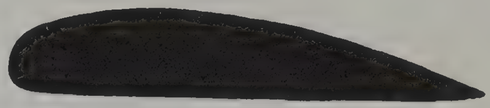


Fig. 1. An Airfoil Section.

How Is Lift Created

What, then, causes this Lift, you may ask.

Let us consider several phenomena produced by the wing moving through the air.

Scientist Daniel Bernouilli discovered that the total energy in any system remains constant **(Bernouilli's Theorem).** In other words, if one element of an energy system is increased, another decreases to counter balance it. Take the example of water flowing through a venturi tube. Being incompressible, the water must speed up to pass through the constricted space of the venturi. The moving water has energy in the form of both pressure and speed. Within the venturi tube, pressure is sacrificed (decreased) to accelerate the speed of the flow.

Air is a fluid, just like water, and can be assumed incompressible insofar as speed aerodynamics is concerned. As such, it acts exactly the same way as water in a venturi tube.

Picture the curved upper surface of a wing as the bottom half of a venturi tube. The upper half of this imaginary tube is the undisturbed airflow above the wing.

Air flowing over the wing's upper surface accelerates as it passes through the constricted area just as it does in the venturi tube. The result is a decrease in pressure on the upper surface of the wing that results in the phenomenon known as lift.

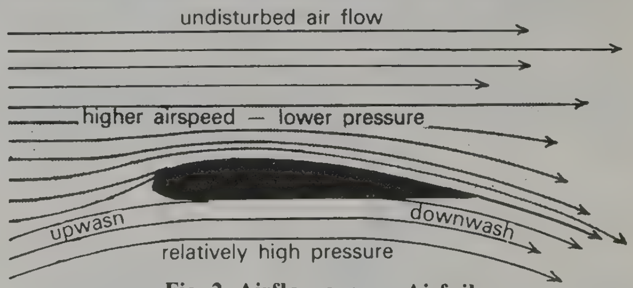


Fig. 2. Airflow over an Airfoil.

The behaviour of air around an airfoil and the resultant phenomenon of lift also obey Newton's Laws of Motion. Air, being a gaseous fluid, possesses inertia, and therefore, according to Newton's First Law, when in motion tends to remain in motion. The introduction of an airfoil into the streamlined airflow alters the uniform flow of air. Newton's Second Law states that a force must be applied to alter the state of uniform motion of air. The airfoil is that force that acts on the air to produce a change of direction. The application of such a force causes an equal and opposite reaction (Newton's Third Law) called, in this case, **lift.**

As the air passes over the wing towards the trailing edge, the air flows not only rearward but downward as well. This flow is called **downwash.** At the same time, the airflow passing under the wing is deflected downward by the bottom surface of the wing. Think of a water ski or surfboard planing over the water. In exerting a downward force upon the air, the wing receives an upward counterforce. Remember Newton's Third Law — for every action there is an opposite and equal reaction. Therefore, the more air deflected downward, the more lift is created. Air is heavy; it weighs 2 pounds per cubic yard at sea level. The reaction produced by the downwash is therefore significant.

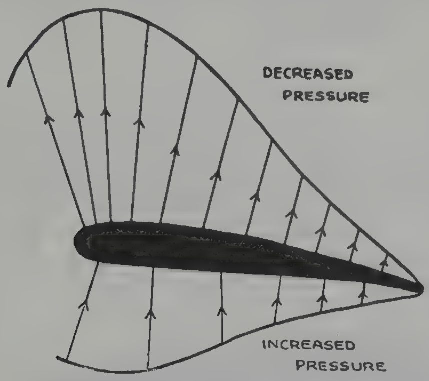


Fig. 3. Pressure Distribution over an Airfoil.

Relative Wind

Relative wind is a term used to describe the direction of the airflow with respect to the wing. If a wing is moving forward and downward, the relative wind is upward and backward. If the wing is moving forward horizontally, the relative wind moves backward horizontally. The flight path and the relative wind are, therefore, always parallel but travel in opposite directions.

Relative wind is created by the motion of the airplane through the air. It is also created by the motion of air past a stationary body or by a combination of both. Therefore, on a take off roll, an airplane is subject to the relative wind created by its motion along the ground and also by the moving mass of air (wind).

However, in flight, only the motion of the airplane produces a relative wind. The direction and speed of the wind have no effect on relative wind.

Angle of Attack and Centre of Pressure

The angle at which the airfoil meets the relative wind is called the **Angle of Attack** (See Fig. 5.).

As the Angle of Attack is *increased,* the changes in pressure over the upper and lower surfaces and the amount of downwash, i.e air deflected downward, **increase** up to a point (the stalling angle). Beyond this angle, they **decrease.** (Fig. 4.)

If we consider all the distributed pressure to be equivalent to a single force, this force will act through a straight line. The point where this line cuts the chord of an airfoil is called the **Centre of Pressure.**

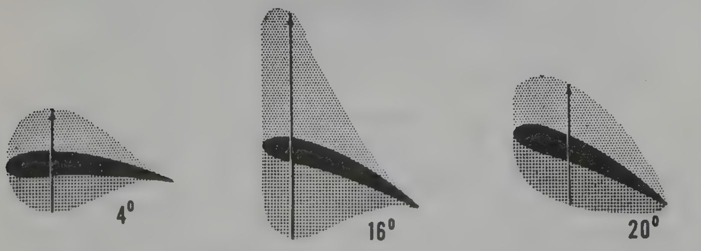


Fig. 4. Change of Pressure Distribution with Angle of Attack.

Note: The envelopes indicated in Fig. 4 do not represent the actual areas of high and low pressure. These exist only in close proximity to the surfaces. They represent the comparative distribution of pressure as determined by pressure plotting. In Fig. 4, the darker shading represents increased pressure, the lighter shading, decreased pressure.

Thus, it will be seen that as the Angle of Attack of an airfoil is increased up to the point of stall, the Centre of Pressure will move forward. Beyond this point, it will move back. The movement of the Centre of Pressure causes an airplane to be unstable.

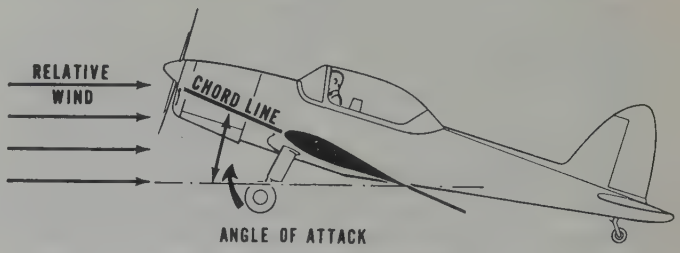


Fig. 5. Angle of Attack.

WEIGHT

The weight of an airplane is the force which acts vertically downward toward the centre of the earth and is the result of gravity.

Just as the lift of an airplane acts through the Centre of Pressure, the weight of an airplane acts through the **Centre of Gravity** (C.G.). This is the point through which the resultant of the weights of all the various parts of the airplane passes, in every attitude that it can assume.

THRUST

Thrust provides the forward motion of the airplane. There are several ways to produce this force — jets, propellers or rockets — but they all depend on the principle of pushing air backward with the object of causing a reaction, or thrust, in the forward direction. The effect is the same whether the thrust is produced by a propeller moving a large mass of air backward at a relatively slow speed or by a jet moving a small mass of air backward at a relatively high speed.

A full description of engines and propellers will be found in the Chapter **Aero Engines.**

DRAG

Drag is the resistance an airplane experiences in moving forward through the air.

For an airplane to maintain steady flight, there must be sufficient lift to balance the weight of the airplane, and there must be sufficient thrust to overcome drag.

Fig. 6 shows an airfoil moving forward through the air and depicts the principle known as the **Resolution of Forces.** The vertical component (OL) is the lift and is used to support the weight of the airplane. The horizontal component (OD) is the drag. OR is the resultant reaction of these two components.

Since drag is a force directly opposed to the motion of the airfoil and, as the work of overcoming it is performed by the engine, it is desirable to have it as small as possible.

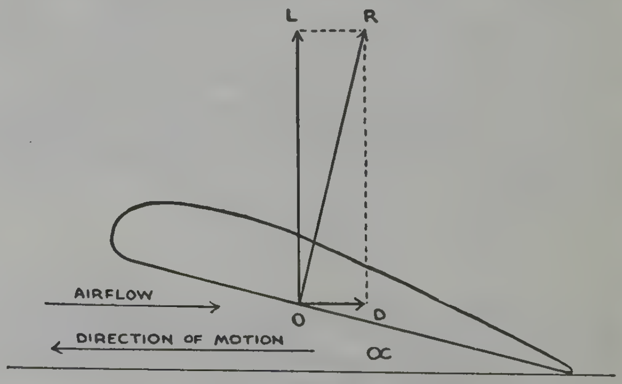


Fig. 6. Forces acting on an Airfoil.

Drag is of two principle types.

1. PARASITE DRAG is the term given to the drag of all those parts of the airplane which do not contribute to lift, that is,

the fuselage, landing gear, struts, antennas, wing tip fuel tanks, etc. In addition, any loss of momentum of the airstream caused by openings, such as those in the cowling and those between the wing and the ailerons and the flaps, add to parasite drag.

Parasite drag may be divided into two components. 1. **Form Drag** refers to the drag created by the form or shape of a body as it resists motion through the air. 2. **Skin Friction** refers to the tendency of air flowing over a body to cling to its surface.

Although parasite drag can never be completely eliminated, it can be substantially reduced. One method is to eliminate altogether those parts of the airplane that cause it. For this reason, retractable landing gear has been developed. Wing struts have been eliminated in favour of fully cantilevered wings. Another method is to streamline those parts that cannot be eliminated. Skin friction can be reduced substantially by the removal of dust, dirt, mud or ice that has collected on the airplane.

Even the most carefully designed individual parts must, however, be joined together to create the total airplane. Resistance caused by the effect of one part on another (i.e. where the wing is attached to the fuselage, or struts to the wings) is called **interference drag** and can be reduced by careful design in the fairing of one shape into another.

2. INDUCED DRAG is caused by those parts of an airplane which are active in producing lift (i.e. the wing). It is the result of the wing's work in sustaining the airplane and is, therefore, a part of the lift and can never be eliminated. It increases as the angle of attack increases and decreases as the angle of attack decreases.

The phenomenon, known as wing tip vortices, is testimony to the existence of induced drag.

As the decreased pressure over the top of the wing is less than the atmospheric pressure around it, the air flowing over the top surface tends to flow **inward.**

The air flowing over the lower surface, due to the lower pressure around it, tends to flow **outward** and curl upward over the wing tip.

When the two airflows unite at the trailing edge, they are flowing contra-wise. Eddies and vortices are formed which tend to unite into one large eddy at each wing tip. These are called **Wing-tip Vortices** and are evidence of induced drag.

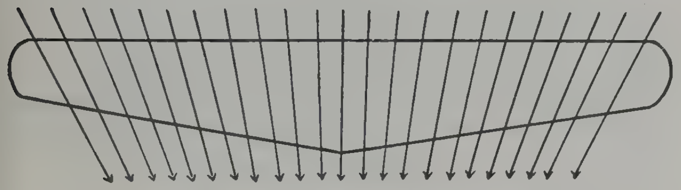


Fig. 7. Airflow over the Top Surface.

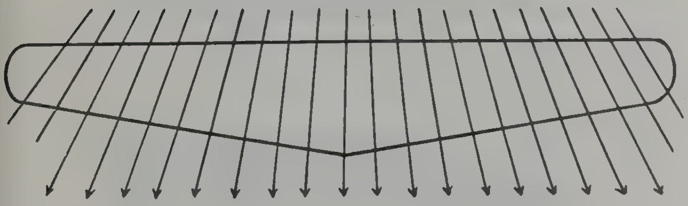


Fig. 8. Air flow over the Bottom Surface.

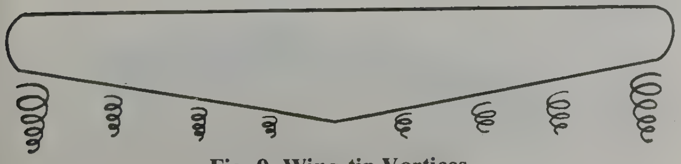


Fig. 9. Wing-tip Vortices.

In order to support the weight of an airplane, a large amount of air must be displaced **downward.** This displaced air must have somewhere to go, and tends to flow **spanwise outwards**, as explained above. It is seeking to escape around the wing tips and flow into the low pressure area created over the upper surface of the wing. It will be obvious that the **heavier** the airplane and the **higher** the span loading on the wing, the more air it will displace downward, therefore the greater will be the circulation of air, and the greater the magnitude of the Wing Tip Vortex created.

The operational aspects of flight in areas where wing tip vortices are present is discussed in the section **"Wake Turbulence"** in Chapter **Airmanship.**

Induced drag does not increase as the speed increases. On the contrary, it is greatest when the airplane is flying slowly, a few mph above the stalling speed when maximum lift is being realized at minimum speed.

The induced drag characteristics of a wing are not the same very near the ground as they are at altitude. During take-off and landing, the induced drag is reduced due to the compression of the air between the wings of the airplane and the ground. This phenomenon is known as **ground effect.** (See **"Ground Effect"** in Chapter **Airmanship.**)

Lift and Drag Curves

As the amount of lift varies with the angle of attack, so too does the drag - hence drag is the price we pay for lift. Thus, although it is desirable to obtain as much lift as possible from a wing, this cannot be done without increasing the drag. It is therefore necessary to find the best compromise.

The lift and drag of an airfoil depend not only on the angle of attack, but also upon:

The shape of the airfoil

The plan area of the airfoil (or wing area) — S.

The square of the velocity (or true airspeed) — V^2.

The density of the air — p.

Hence the lift of an airfoil can be expressed as a formula by: $C_L . \frac{1}{2} p V^2 . S$

And the drag by: $C_D . \frac{1}{2} p V^2 . S$

The symbols C_L and C_D represent the **Lift Coefficient** and **Drag Coefficient** respectively. They depend on the shape of the airfoil and will alter with changes in the angle of attack.

The **Lift-Drag Ratio** is used to express the relation between lift and drag and is obtained by dividing the Lift Coefficient by the Drag Coefficient. $\frac{C_L.}{C_D.}$

The characteristics of any particular airfoil section can conveniently be represented by curves on a graph showing the amount of lift and drag obtained at various angles of attack, the Lift-Drag Ratio, and the movement of the Centre of Pressure. (Fig. 10.)

Notice that the Lift Curve (C_L) reaches its maximum for this particular wing section at 18° angle of attack, and then rapidly decreases. 18° is therefore the stalling angle.

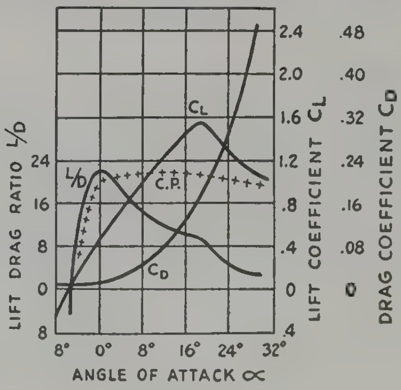


Fig. 10.

The Drag Curve (CD) increases very rapidly from 14° angle of attack — completely overcoming the lift at 22° angle of attack.

The Lift-Drag Ratio (L/D) reaches its maximum at 0° angle of attack, meaning that at this angle we obtain the most lift for the least amount of drag.

The C.P. moves gradually forward till 12° angle of attack is reached, and from 18° commences to move back.

Note: The curves in Fig. 10 are for a particular airfoil section, the Clark Y. The values of CL, CD and L/D Ratio vs. angle of attack will differ for every individual airfoil design. The general appearance of the co-ordinates in Fig. 10, however, is similar throughout a wide range of airfoil sections employed by aircraft designers today.

Streamlining

In this age when everything from trains to children's toys is streamlined, it hardly seems necessary to explain what streamlining means. Basically, streamlining is a design device by which a body is so shaped that drag is minimized as the body moves forward through the air. A flat plate or a round ball moving through the air disturb the smooth flow of air and set up eddies behind them. The effect of streamlining an object can be seen in Fig. 11.

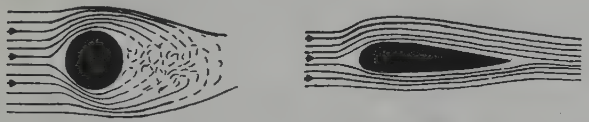


Fig. 11. Effects of streamlining.

Aileron Drag

In banking to make an airplane turn, one aileron is depressed and the other is raised. The downgoing aileron, being depressed into the compressed airflow on the underside of the wing, causes drag. The upgoing aileron, moving up into a more streamlined position, causes less drag. The drag on the downgoing aileron is known as **Aileron Drag** and if not corrected for in the design of the aileron, tends to cause a yaw in the opposite direction to which the bank is applied.

Both **Frise** and **Differential Ailerons** have been designed to overcome aileron drag.

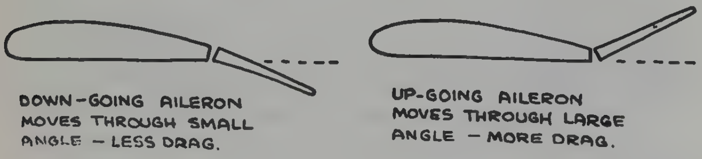

DOWN-GOING AILERON MOVES THROUGH SMALL ANGLE - LESS DRAG.
UP-GOING AILERON MOVES THROUGH LARGE ANGLE - MORE DRAG.

Fig. 12. Differential Ailerons.

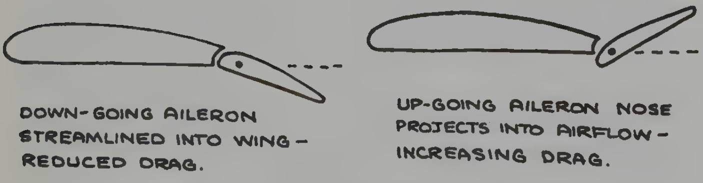

DOWN-GOING AILERON STREAMLINED INTO WING - REDUCED DRAG.
UP-GOING AILERON NOSE PROJECTS INTO AIRFLOW - INCREASING DRAG.

Fig. 13. Frise Ailerons.

The Boundary Layer

The Boundary Layer is a very thin sheet of air lying over the surface of the wing (and, for that matter, all other surfaces of the airplane). Because air has viscosity, this layer of air tends to adhere to the wing. As the wing moves forward through the air, the boundary layer at first flows smoothly over the streamlined shape of the airfoil. Here the flow is called the **Laminar Layer.**

As the boundary layer approaches the centre of the wing, it begins to lose speed due to skin friction and it becomes thicker and turbulent. Here it is called the **Turbulent Layer.** The point at which the boundary layer changes from laminar to turbulent is called the **Transition Point** (Fig. 14). Where the boundary layer becomes turbulent, drag due to skin friction is relatively high.

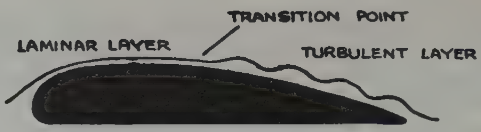
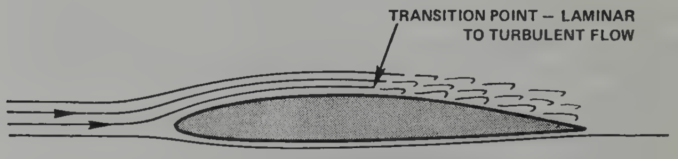


Fig. 14. Laminar and Turbulent Layer.

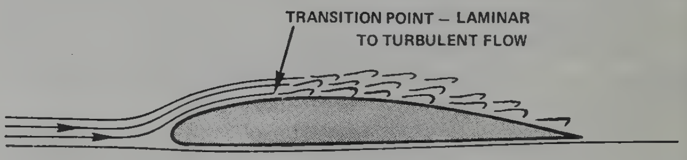
Various methods have been developed to control the boundary layer in order to reduce skin friction drag.

Suction Method. One method uses a series of thin slots in the wing running out from the wing root towards the tip. A vacuum sucks the air down through the slots, preventing the airflow from breaking away from the wing and forcing it to follow the curvature of the wing surface. The air, which is sucked in, siphons through the ducts inside the wing and is exhausted backwards to provide extra thrust.

The **Laminar Flow Airfoil** is itself a structural design intended to make possible better boundary layer control. The thickest part of a laminar flow wing occurs at 50% chord. The transition point at which the laminar flow of air breaks down into turbulence is at or near the thickest part. As can be seen in the accompanying illustration, the transition point at which the laminar flow of air becomes turbulent on a laminar flow airfoil is rearward of that same point on a conventional designed airfoil.



TRUE LAMINAR FLOW WING



"ORDINARY" WING

Fig. 15.

Vortex generators (Fig.16) are small plates about an inch deep standing on edge in a row spanwise along the wing. They are placed at an angle of attack and (like a wing airfoil section) generate *vortices.* These tend to prevent or delay the breakaway of the boundary layer by *re-energizing* it. They are lighter and simpler than the suction boundary layer control system described above.

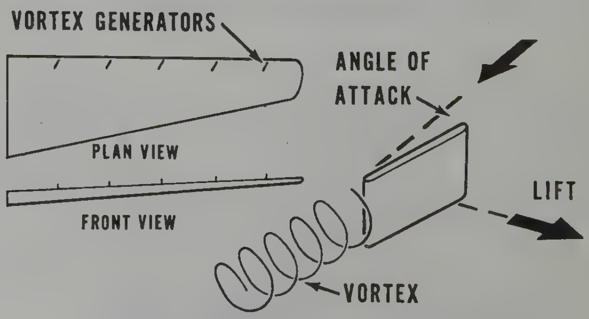


Fig. 16. Vortex Generators.

COUPLES

The principle of equilibrium has already been introduced at the beginning of this chapter in the discussion of the forces that act on an airplane in flight. When two forces, such as Lift and Drag, are equal and opposite, but parallel rather than passing through the same point, they are said to form a **Couple.**

A Couple will cause a **Turning Moment** about a given axis as in Fig.17.

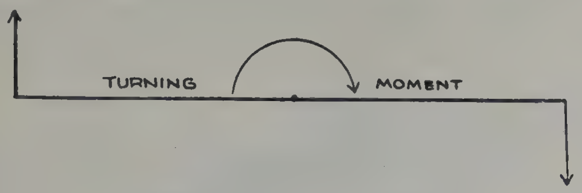


Fig. 17. Effect of a Couple

If Weight is ahead of Lift, the Couple created will turn the nose of the airplane down. Conversely, if Lift is ahead of Weight, the Couple created will turn the nose of the airplane up.

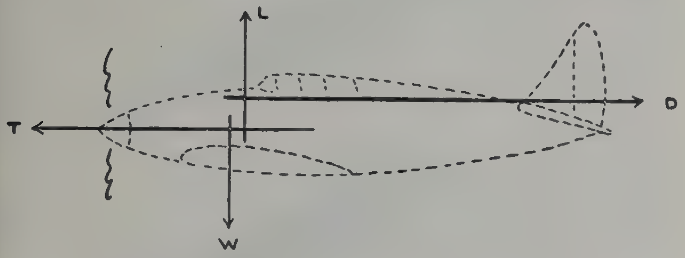


Fig. 18. Forces acting on an Airplane in Flight.

If Drag is above Thrust, the Couple formed will turn the nose of the airplane up. Conversely, if Thrust is above Drag, the Couple formed will turn the nose of the airplane down.

Notice that in Fig. 18, Forces acting on an Airplane in Flight, Weight is placed ahead of Lift, and Drag is above Thrust. As a result, when the engine is shut off, and there is no Thrust, the Couple due to Weight and Lift will naturally tend to turn the nose down.

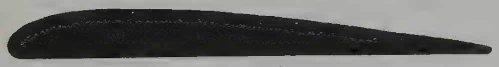
In the case of flying boat design, it is practically impossible to have the Drag above the Thrust. Therefore Lift must be placed ahead of Weight for normal flight. This leads to the unsatisfactory tendency, when the engine is shut off, to nose up, with the consequent risk of stalling in the hands of an inexperienced pilot.

DESIGN OF THE WING

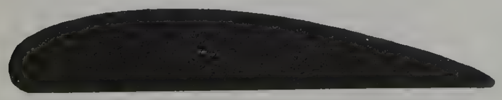
The type of operation for which an airplane is intended has a very important bearing on the selection of the shape and design of the wing for that airplane. If the airplane is designed for low speed, a thick airfoil is most efficient. A thin airfoil is best for high speed.

CONVENTIONAL AIRFOILS

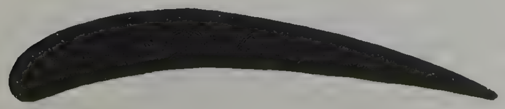
The following illustrations depict a selection of designs of airfoil sections. These are known as conventional airfoils.



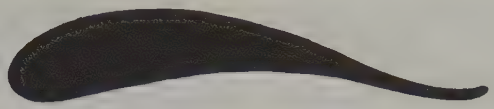
Low camber—low drag—high speed—thin wing section suitable for race planes, fighters, interceptors, etc.



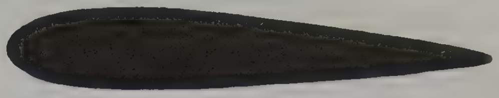
Deep camber — high lift — low speed —thick wing section suitable for transports, freighters, bombers, etc.



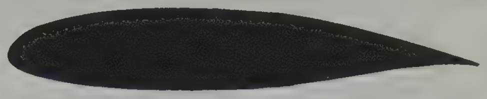
Deep camber — high lift — low speed — thin wing section suitable as above.



Low lift — high drag — reflex trailing edge wing section. Very little movement of centre of pressure. Good stability.



Symmetrical (cambered top and bottom) wing sections. Similar to above.



New GA(W)-1 airfoil—thicker for better structure and lower weight—good stall characteristics—camber is maintained farther rearward which increases lifting capability over more of the airfoil and decreases drag.

LAMINAR AIRFOILS

There is another type of airfoil in common use on modern airplanes. It is a fairly recent development and is known as the **Laminar Flow Airfoil.**

Laminar flow airfoils were originally developed for the purpose of making an airplane fly faster. This was achieved by cutting down drag since the laminar airfoil takes less energy to slide through the air. As an extra benefit, there was the design advantage in that the laminar airfoil has only one spar.

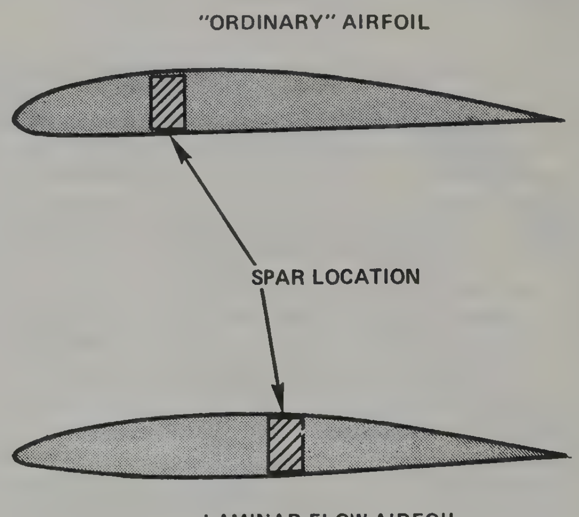


Fig. 19.

The major difference between the two types of airfoil is this: the thickest part of a laminar wing occurs at 50% chord while in the conventional design the thickest part is at 25% chord.

PLANFORM

Planform refers to the shape of the wing as seen from directly above. Wings may be rectangular or elliptical or delta shaped. Some wings taper from wing root to wing tip, with the taper along the leading edge or along the trailing edge or, in some cases, with a taper along both edges.

The **Aspect Ratio** of a wing is the relationship between the length or span of the wing and its width or chord. It is computed by dividing the span by the average chord (the Mean Aerodynamic Chord MAC).

A wing, for example, that has a span of 24 feet and a chord of 6 feet has an aspect ratio of 4. A wing with a span of 36 feet and a chord of 4 feet has an aspect ratio of 9. The actual size, in area, of both wings is identical (144 sq.ft.) but their flight performance is quite different because of their differing aspect ratios.

A wing with a high aspect ratio will generate more lift and less induced drag than a wing with a low aspect ratio.

For this reason, gliders have wings with high aspect ratios.

ANGLE OF INCIDENCE

The **Angle of Incidence** is the angle at which the wing is permanently inclined to the longitudinal axis of the airplane.

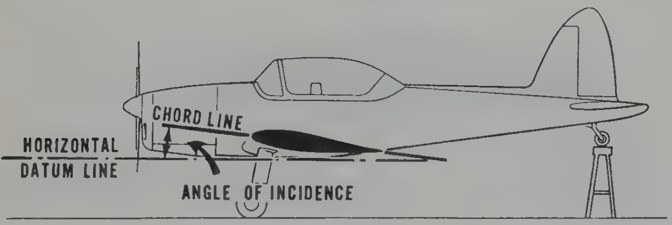


Fig. 20. Angle of Incidence.

Choosing the right angle of incidence can improve flight visibility, enhance take-off and landing characteristics and reduce drag in level flight.

The angle of incidence that is usually chosen is the angle of attack at which the lift-drag ratio is optimum. See Fig. 10. In most modern airplanes, there is a small positive angle of incidence so that the wing has a slight angle of attack when the airplane is in level cruising flight.

WASHOUT

To reduce the tendency of the wing to stall suddenly as the stalling angle is approached, designers incorporate in wing design a feature known as "washout". The wing is twisted so that the angle of incidence at the wing tip is less than that at the root of the wing. As a result, the wing has better stall characteristics in that the section towards the root will stall before the outer section of the wing. The ailerons, located towards the wing tips, are still effective even though part of the wing is stalled.

The same improved stall characteristics are achieved by the device of changing the airfoil shape from the root to the tip. The manufacturer incorporates a wing shape at the tip which has the characteristic of stalling at a slightly higher angle of attack.

WING FENCES

Wing fences are fin like vertical surfaces attached to the upper surface of the wing, that are used to control the airflow. On swept wing airplanes, they are located about two-thirds of the way out towards the wing tip and prevent the drifting of air toward the tip of the wing at high angles of attack. On straight wing airplanes, they control the airflow in the flap area. In both cases, they give better slow speed handling and stall characteristics.

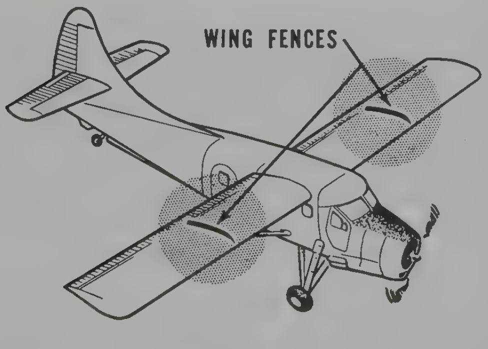


Fig. 21. Wing Fences.

SLOTS AND SLATS

Slats are auxiliary airfoils fitted to the leading edge of the wing. At high angles of attack they automatically move out ahead of the wing. The angle of attack of the slat being less than that of the mainplane, there is a smooth airflow over the slat which tends to smooth out the eddies forming over the wing. Slats are usually fitted to the leading edge near the wing tips to improve lateral control.

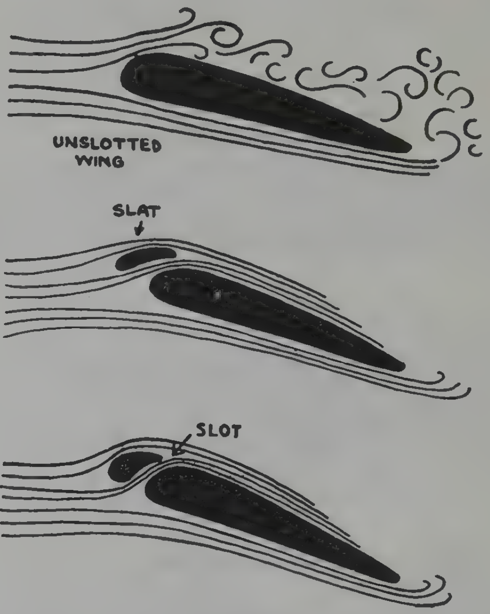


Fig. 22. Slotted Wings.

Slots are passageways built into the wing a short distance from the leading edge in such a way that at high angles of attack the air flows through the slot and over the wing, tending to smooth out the turbulence due to eddies.

SPOILERS

Spoilers are devices fitted to the wing which increase drag and decrease lift. They usually consist of a long narrow strip of metal arranged spanwise along the top surface of the airfoil. In some airplanes, they are linked to the ailerons and work therefore in unison with the ailerons for lateral control. As such, they open on the side of the upgoing aileron, spoil the lift on that wing and help drive the wing down and the airplane to roll into a turn.

In some airplanes, spoilers have replaced ailerons as a means of roll control. The spoiler moves only upward in contrast to the aileron that moves upward to decrease lift and downward to increase lift. The spoiler moves only up, spoiling the wing lift. By using spoilers for roll control, full span flaps can be used to increase low speed lift.

Spoilers can also be connected to the brake controls and, when so fitted, work symmetrically across the airplane for producing drag and destroying lift after landing, thereby transferring all the weight of the airplane to the wheels and making braking action more effective.

FLAPS

Flaps are high lift devices which, in effect, increase the camber of the wing and, in some cases, as with the Fowler Flap, also increase the effective wing area. Their use gives better take-off performance and permits steeper approach angles and lower approach and landing speeds.

When deflected, flaps increase the upper camber of the wing, increasing the negative pressure on the top of the wing. At the same time, they allow a build up of pressure below the wing. During take-off, flap settings of 10° to 20° are used to give better take-off performance and a better angle of climb, especially valuable when climbing out over obstacles.

However, not all airplane manufacturers recommend the use of flaps during take-off. They can be used only on those airplanes which have sufficient take-off power to overcome the extra drag that extended flaps produce. The recommendations of the manufacturer should, therefore , always be followed.

Flaps do indeed increase drag. The greater the flap deflection, the greater the drag. At a point of about half of their full travel, the increased drag surpasses the increased lift and the flaps become "airbrakes". Most flaps can be extended to 40° from the chord of the wing. At settings between 20° and 40°, the essential function of the flaps is to improve the landing capabilities, by steepening the glide without increasing the glide speed. In an approach over obstacles, the use of flaps permits the pilot to touch down much nearer the threshold of the runway. Flaps also permit a slower landing speed and act as airbrakes when the airplane is rolling to a stop after landing, thus reducing the need for excessive braking action. As a result, there is less wear on the undercarriage, wheels and tires. Lower landing speeds also reduce the possibility of ground looping during the landing roll.

Plain and Split Flaps increase the **lift** of a wing, but at the same time, they greatly increase the **drag.** For all practical purposes they are of value only in approach and landing. They should not normally be employed for take-off because the extra drag reduces acceleration.

Slotted Flaps, on the other hand, including such types as Fowler and Zap, produce **lift** in excess of **drag** and their partial use is therefore recommended for take-off.

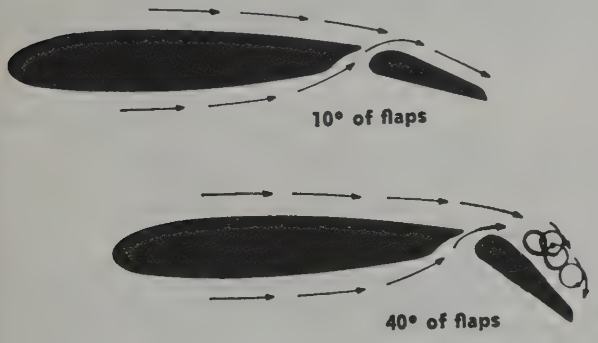


Fig. 23 .

From the standpoint of aerodynamic efficiency, the Fowler Flap is generally considered to offer the most advantages and the fewest disadvantages, especially on larger airplanes, while double slotted flaps have won wide approval for smaller types.

On STOL airplanes, a combination of double slotted flaps and leading edge slats are common.

Changes in flap setting affect the trim of an airplane. As flaps are lowered, the Centre of Pressure moves rearward creating a nose down, pitching moment. However, in some airplanes, the change in airflow over the tailplane as flaps are lowered is such that the **total** moment created is nose-up and it becomes necessary to trim the airplane "nose down".

The airplane is apt to lose considerable height when the flaps are raised. At low altitudes, therefore, the flaps should be raised cautiously.

Most airplanes are placarded to show a *maximum speed above which the flaps must not be lowered.* The flaps are not designed to withstand the loads imposed by high speeds. Structural failure may result from severe strain if the flaps are selected "down" at higher than the specified speed.

When the flaps have been lowered for a landing, they should not ordinarily be raised until the airplane is on the ground. If a landing has been missed, the flaps should not be raised until the power has been applied and the airplane has regained normal climbing speed. It is then advisable to raise the flaps in "stages".

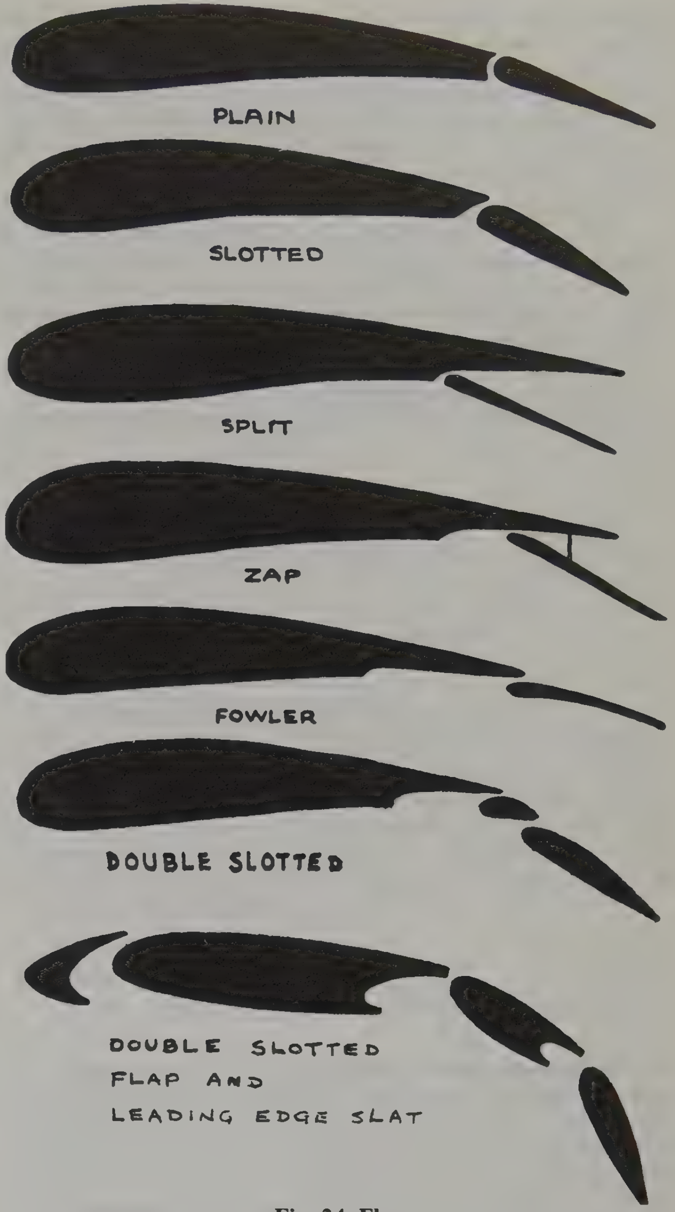


Fig. 24. Flaps.

How much flap should be used in landing? The use of flaps affects the wing airfoil in two ways—they increase both lift and drag. The greater lift results in a lower stalling speed and permits a lower touchdown speed. The greater drag permits a steeper approach angle without increasing airspeed. The extra drag of full flaps results in a shorter landing roll. All these factors mean less strain on the tires and brakes, less strain on the landing gear and greater control of the airplane during the landing roll.

On the other hand, in a cross wind condition, the flaps present a greater surface for the wind to act upon when the airplane is rolling on the ground. A cross wind acting on full flaps increases the weather vaning tendency. In addition the wing on the side from which the wind is blowing will tend to rise. It is important, therefore, to continue a follow through cross wind correction during the landing roll.

THE AXES OF AN AIRPLANE

There are three axes around which the airplane moves. These axes all pass through the airplane's Centre of Gravity, which is that point which is the centre of the airplane's total weight.

The **Longitudinal Axis** extends lengthwise through the fuselage from the nose to the tail. Movement of the airplane around the longitudinal axis is known as **roll** and is controlled by movement of the ailerons. To move the ailerons, the pilot turns the control wheel either clockwise or counter clockwise (or moves the control column either right or left). This action lowers the aileron on one wing and raises the aileron on the other wing. The downgoing aileron increases the camber of its wing, producing more lift and the wing rises. The upgoing aileron spoils the airflow on its wing, decreases the lift and the wing descends. The airplane rolls into a turn.

The **Lateral Axis** extends crosswise from wing tip to wing tip. Movement of the airplane around the lateral axis is known as **pitch** and is controlled by movement of the elevators. To effect a nose down attitude, the pilot pushes forward on the control wheel or stick. The elevator deflects downward, increasing the camber of the horizontal tail surface and thereby increasing the lift on the tail. To effect a nose up attitude of the airplane, the pilot pulls the wheel toward him, the elevators are deflected upwards decreasing the lift on the tail, with a resultant downward movement of the tail.

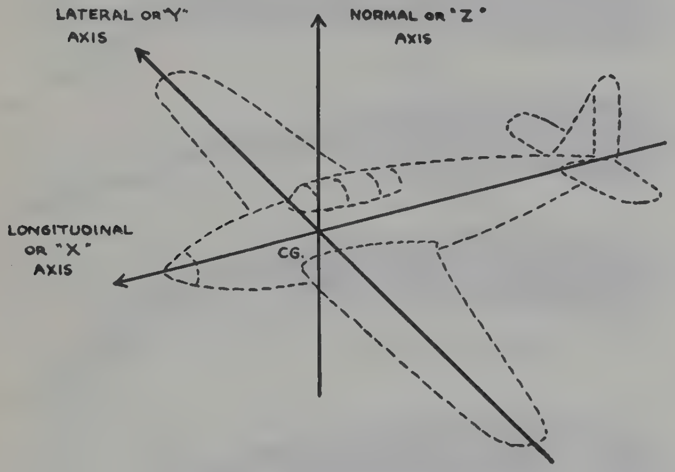


Fig. 25. The Axes of An Airplane.

The **Vertical or Normal Axis** passes vertically through the Centre of Gravity. Movement of the airplane around the vertical axis is **yaw** and is controlled by movement of the rudder. Pressure applied to the left rudder pedal, for example, deflects the rudder to the left into the airflow. The pressure of the airflow against the rudder pushes the tail to the right. The nose of the airplane yaws to the left.

There is a distinct relationship between movement around the vertical and longitudinal axes of an airplane (i.e. yaw and roll). When rudder is applied to effect a yaw, for example, to the right, the left wing (on the outside of the turn) moves faster than the inside wing, meets the relative air at a greater angle of attack and at greater speed and produces more lift. The use of rudder, therefore, along with aileron can help to raise the wing and produce a better co-ordinated turn.

In a roll, the airplane has a tendency to yaw away from the intended direction of the turn. This tendency is the result of aileron drag and is called **adverse yaw**. The upgoing wing, as well as gaining more lift from the increased camber of the downgoing aileron, also experiences more induced drag. The airplane, as a result, skids outward on the turn. Use of rudder in the turn corrects this tendency.

BALANCED CONTROLS

Controls are sometimes dynamically balanced to assist the pilot to move them. Several of the various means by which an aerodynamic reaction is used to serve this purpose are illustrated in Fig. 26.

By having some of the control surface in front of the hinge, the air striking the front portion helps to move the control surface in the required direction. The design also helps to counteract adverse yaw when used in aileron design.

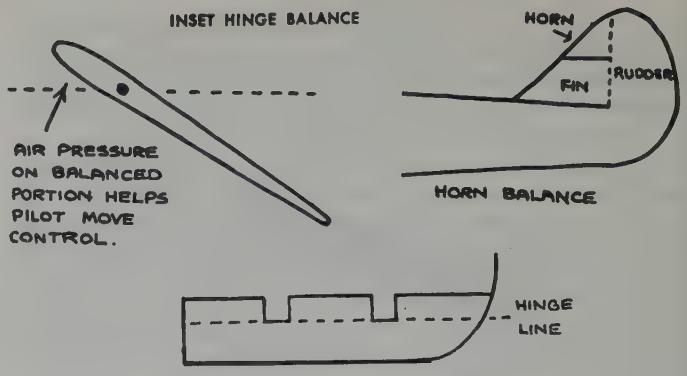


Fig. 26. Dynamic Balance.

STABILITY

An airplane in flight is constantly subjected to forces that disturb it from its normal horizontal flight path. Rising columns of hot air, downdrafts, gusty winds, etc., make the air "bumpy" and the airplane is thrown off its course. Its nose or tail drops or one wing dips. How the airplane reacts to such a disturbance from its flight attitude depends on its **stability** characteristics.

Stability is the tendency of an airplane in flight to remain in straight, level, upright flight and to return to this attitude, if displaced, without corrective action by the pilot.

Static Stability is the *initial* tendency of an airplane, when disturbed, to return to the original position. (The initial "wave" motion in Fig. 27.)

Dynamic Stability is the *overall* tendency of an airplane to return to its original position, following a series of damped out oscillations. (The diminishing "wave" pattern in Fig.27).

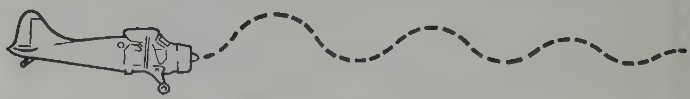


Fig. 27. Static and Dynamic Stability.

Stability may be (a) **Positive**, meaning the airplane will develop forces or moments which tend to restore it to its original position. (b) **Neutral**, meaning the restoring forces are absent and the airplane will neither return from its disturbed position, nor move further away. (c) **Negative**, meaning it will develop forces or moments which tend to move it further away. Negative Stability is, in other words, the condition of **Instability.**

A stable airplane is one that will fly "hands off" and is pleasant and easy to handle. An exceedingly stable airplane, on the other hand, may lack maneuverability.

An airplane which, following a disturbance, oscillates with increasing up and down movements until it eventually stalls or enters a dangerous dive would be said to be unstable, or to have Negative Dynamic Stability.

An airplane may be *inherently stable*, that is, stable due to features incorporated in the design, but may become *unstable* due to changes in the position of the Centre of Gravity (caused by consumption of fuel, improper disposition of the disposable load, etc.).

Stability may be (a) **Longitudinal** (b) **Lateral** or (c) **Directional**, depending on whether the disturbance has affected the airframe in the (a) Pitching (b) Rolling, or (c) Yawing Plane.

LONGITUDINAL STABILITY

Longitudinal stability is pitch stability, or stability around the lateral axis of the airplane.

To obtain longitudinal stability, airplanes are designed to be nose-heavy when correctly loaded. The Centre of Gravity is ahead of the Centre of Pressure. This design feature is incorporated so that, in the event of engine failure, the airplane will assume a normal glide. It is because of this nose heavy characteristic that the airplane requires a tailplane. Its function is to resist this diving tendency. The tailplane is set at an angle of incidence that produces a negative lift and thereby, in effect, holds the tail down. In level, trimmed flight, the nose heavy tendency and the negative lift of the tailplane exactly balance each other.

Two principle factors influence Longitudinal Stability: 1. Size and Position of the Horizontal Stabilizer, and 2. Position of the Centre of Gravity.

The Horizontal Stabilizer

The tail plane, or stabilizer, is placed on the tail end of a lever arm (the fuselage) is provide longitudinal stability. It may be quite small. However, being situated at the end of the lever arm, it has great leverage. When the angle of attack on the wings is increased by a disturbance, the Centre of Pressure moves forward, tending to turn the nose of the airplane up and the tail down. The tailplane, moving down, meets the air at a greater angle of attack, obtains more lift and tends to restore the balance.

On most airplanes, the stabilizer appears to be set at an angle of incidence that would produce an upward lift on the tailplane. It must, however, be remembered that the tailplane is in a position to be in the downwash from the wings. The air that strikes the stabilizer has already passed over the wings and been deflected slightly downward. The angle of the downwash is about half the angle of attack of the main airfoils. The proper angle of incidence of the stabilizer therefore is very important in order for it to be effective in its function.

Centre of Gravity

The Centre of Gravity is, of course, very important in achieving longitudinal stability. If the airplane is loaded, with the Centre of Gravity too far aft, the airplane may assume a nose up rather than a nose down attitude. The inherent stability will be lacking and, even though down elevator may correct the situation, control of the airplane in the longitudinal plane will be difficult and perhaps, in extreme cases, impossible.

LATERAL STABILITY

Lateral Stability is stability around the longitudinal axis, or roll stability.

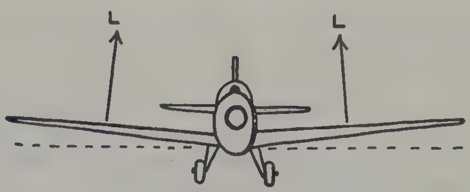
Lateral Stability is achieved through 1. Dihedral, 2. Sweepback, 3. Keel Effect, and 4. Proper distribution of Weight.

Dihedral

The Dihedral Angle is the angle that each wing makes with the horizontal (Fig. 28). The purpose of Dihedral is to improve lateral stability. If a disturbance causes one wing to drop, the unbalanced force (Fig. 28) produces a sideslip in the direction of the downgoing wing. This will, in effect, cause a flow of air in the opposite direction to the slip. This flow of air will strike the lower wing at a greater angle of attack than it strikes the upper wing. The lower wing will thus receive more lift and the airplane will roll back into its proper position.

Since Dihedral inclines the wing to the horizontal, so too will the Lift Reaction of the wing be inclined from the vertical (Fig. 28). Hence an excessive amount of Dihedral will, in effect, reduce the Lift Force opposing Weight.

Some modern airplanes have a measure of negative dihedral, or **anhedral**, on the wings and/or stabilizer. The incorporation of this feature provides some advantages in overall design in certain types of airplanes. However, it does have an effect, probably adverse, on lateral stability.



Dihedral.

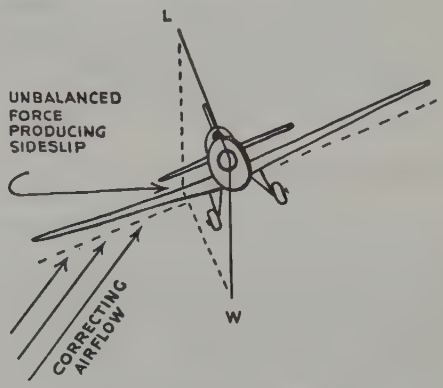


Fig. 28. Effect of Dihedral.

Keel Effect

Dihedral is more usually a feature on low wing airplanes, although some dihedral may be incorporated in high wing airplanes as well.

Most high wing airplanes are laterally stable simply because the wings are attached in a high position on the fuselage and because the weight is therefore low. When the airplane is disturbed and one wing dips, the weight acts as a pendulum returning the airplane to its original attitude.

Sweepback

A sweptback wing is one in which the leading edge slopes backward.

When a disturbance causes an airplane with sweepback to slip or drop a wing, the low wing presents its leading edge at an angle that is perpendicular to the relative wind. As a result, the low wing acquires more lift, rises and the airplane is restored to its original flight attitude.

Sweepback also contributes to directional stability. When turbulence or rudder application causes the airplane to yaw to one side (for example, the left as in Fig. 29), the right wing (B) presents a longer leading edge perpendicular to the relative wind. The airspeed of the right wing increases and it acquires more drag than the left wing (A). The additional drag on the right wing pulls it back, yawing the airplane back to its original flight path.

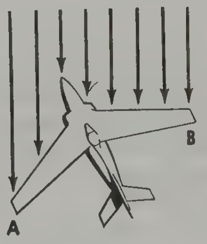


Fig. 29. Sweepback.

DIRECTIONAL STABILITY

Directional Stability is stability around the vertical or normal axis.

The most important feature that affects directional stability is the vertical tail surface, that is, the fin and rudder. Keel effect and sweepback also contribute to directional stability to some degree.

The Fin

An airplane has the tendency always to fly head on into the relative wind. This tendency which might be as described as weather vaning is directly attributable to the vertical tail fin and to some extent also the vertical side areas of the fuselage. If the airplane yaws away from its course, the airflow strikes the vertical tail surface from the side and forces it back to its original line of flight. In order for the tail surfaces to function properly in this weather vaning capacity, the side area of the airplane aft of the Centre of Gravity must be greater than the side area of the airplane forward of the C.G. If it were otherwise, the airplane would tend to rotate about its vertical axis.

FLIGHT PERFORMANCE

TORQUE

The propeller usually rotates clockwise, as seen from the pilot's seat. The reaction to the spinning propeller causes the airplane to rotate counter clockwise, to the left. This left turning tendency is called **torque.** The designer of the airplane compensates for torque in cruising flight by building a slight right turning tendency into the airplane. For example, the left wing may have a slightly greater angle of incidence than the right wing. Aileron trim tabs also are used to compensate for torque.

On take-off, torque affects directional control. Use of right rudder during the take-off roll corrects this condition.

ASYMMETRIC THRUST

Another left turning tendency is the result of **asymmetric thrust**, or **P. Factor.** At high angles of attack and high power settings, such as during take-off, the descending blade of the propeller (on the pilot's right) has a greater angle of attack than the ascending blade. This situation produces more lift from the right side of the propeller with a consequent yawing to the left. Right rudder pressure compensates for this tendency. Asymmetric thrust is significant only at high angles of attack. In level flight, both blades of the propeller meet the relative wind equally and produce equal thrust.

PRECESSION

The spinning propeller of an airplane acts like a gyroscope. One of the characteristics of a gyroscope is **rigidity in space**; that is, the rotating gyro tends to stay in the same plane of rotation and resists any change in that plane. If forced to change, precession results.

If an airplane changes suddenly from a nose up to a nose down position, as is the case during the take-off roll in a tail wheel airplane, the airplane will yaw sharply to the left as the pilot shoves the wheel forward to raise the tail. The application of right rudder compensates for the precession tendency.

SLIPSTREAM

The air pushed backward by a revolving propeller has a corkscrew motion. This causes an **increased** pressure on one side of the tail unit, and a **decreased** pressure on the other side. The tail is consequently pushed sideways from the high pressure side towards the low—causing the airplane to yaw. The condition is corrected by offsetting the fin, or by offsetting the engine thrust line, or by fitting trim tabs on the rudder, or by a combination of two or all of these methods. In some airplanes, the rudder trim is adjustable by a control in the cockpit. In this way, the pilot is better able to compensate for the changes in the pressure on the rudder as the airplane changes from climbing power, to cruise, to gliding.

This revolving slipstream from the propeller causes an airplane, especially tailwheel airplanes, as the throttle is opened to commence the take-off roll, to yaw to the left. As the airspeed increases, the tendency is less pronounced. Right rudder compensates.

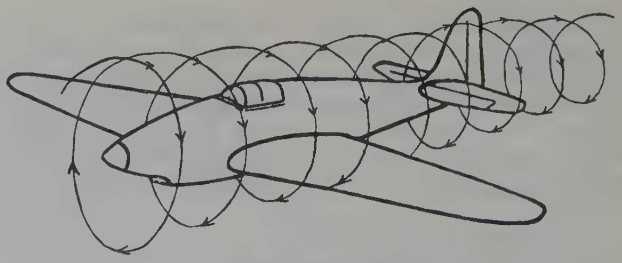


Fig. 30. Slipstream.

It may be of interest at this point to mention the relative effects of the slipstreams of pusher and tractor type propellers. The tractor type of propeller located at the nose of the airplane pushes high speed turbulent air back over the airplane, thereby increasing considerably the drag of the fuselage and wing root sections. A pusher type of propeller located at the rear of the plane, therefore, allows better high speed performance due to the reduction of this drag. Because the tractor propeller bites into "clean" air, its efficiency is good whereas the pusher propeller bites into disturbed air. Nevertheless, from the standpoint of overall efficiency, the pusher propeller configuration is considered to have more to offer in performance benefits.

CLIMBING

During level flight, the engine must produce a thrust equal to the drag of the airplane for the airplane to be in a state of equilibrium. If the power is increased, the pilot can maintain level flight at an increased speed by putting the nose down slightly (i.e. decreasing the angle of attack). If the pilot does not change the angle of attack, the airplane will begin to climb as a result of the increased thrust, since the increased speed of the relative wind over the airfoils will produce more lift. By adjusting power (i.e. choosing any setting between that needed for normal, straight and level cruise and full power) and by varying the angle of attack, the pilot can flatten or steepen the angle of climb and the airspeed in the climb.

Once established in a steady state of climb condition, the airplane is again in a state of equilibrium. In the climb attitude, the airplane is inclined away from the horizontal and, as a result, part of the weight acts rearward and combines with drag. Thrust, therefore, equals drag plus a component of weight and lift equals weight less that component of weight that is acting rearward.

The ability of an airplane to climb is dependent on the extra power that is available from the engine. At ever increasing altitudes, the density of the air decreases and the power of the engine drops off. The climb, therefore, becomes increasingly more shallow as greater altitudes are reached until further climbing is impossible. The airplane has then reached its **absolute ceiling.**

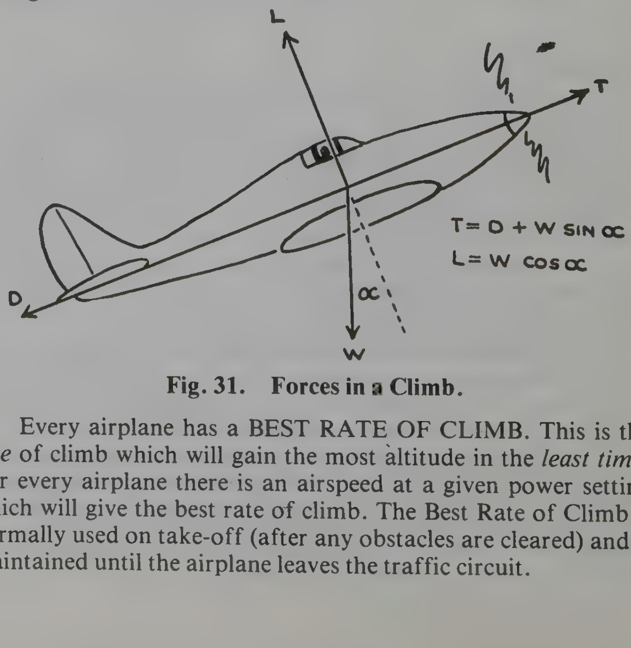


Fig. 31. Forces in a Climb.

Every airplane has a BEST RATE OF CLIMB. This is the *rate* of climb which will gain the most altitude in the *least time*. For every airplane there is an airspeed at a given power setting which will give the best rate of climb. The Best Rate of Climb is normally used on take-off (after any obstacles are cleared) and is maintained until the airplane leaves the traffic circuit.

The BEST ANGLE OF CLIMB is the *angle* which will gain the most altitude in a *given distance.* It is valuable in climbing out of restricted areas over obstacles. The airspeed for the steepest angle of climb is somewhat lower than the speed at which the best rate of climb is obtained. Because the airspeed for the Best Angle of Climb is relatively slow, there is less air circulating around the engine to provide cooling and engine overheating is possible. The Best Angle of Climb, therefore, should be maintained only until obstacles are cleared and then the nose of the airplane should be lowered to pick up the Best Rate of Climb airspeed.

Every pilot should determine the Best Rate of Climb Speed and Best Angle of Climb Speed for the particular airplane he is flying. These airspeeds are usually given in the Airplane Flight Manual. However, it is necessary to bear in mind that these speeds will vary according to the all-up-weight of the airplane.

The rate of climb is not affected by the wind, since it is a *vertical* measurement of airplane performance and is not in any way related to groundspeed.

The angle of climb, on the other hand, is appreciably affected by the wind. When climbing into wind, the airplane moves over the ground at a lower speed and hence takes longer to cover a given forward distance. The stronger the wind, the slower the ground speed, and hence the steeper the angle of climb.

NORMAL CLIMB is a rate of climb that should be used in any prolonged cruise climb. The airspeed for Normal Climb is always indicated in the Airplane Flight Manual. It is a speed that is usually 5 to 10 knots faster than the Best Rate of Climb Airspeed and as such provides better engine cooling, easier control and better visibility over the nose.

GLIDING

In gliding, there is no power from the engine and the airplane is under the influence of gravity. Of the four forces, thrust is now absent and a state of equilibrium must be maintained by lift, drag and weight only.

In Fig. 32. Forces in a Glide, R represents the Total Reaction, i.e. Resultant of Lift and Drag. This is equal and opposite to Weight.

The angle at which the pilot chooses to glide determines the airspeed in the glide. The steeper the angle, the faster the airspeed; the shallower the angle, the slower the airspeed. At too fast an airspeed, structural damage to the airframe could result. At too slow an airspeed, the airplane could stall. The pilot must, therefore, choose a gliding angle that maintains an airspeed that is sufficient to maintain flight but not too fast to be unsafe.

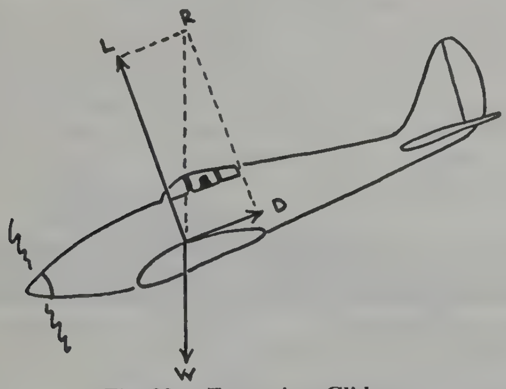


Fig. 32. Forces in a Glide.

Gliding Angle

An airplane will glide the farthest distance at the airspeed which gives the best lift-drag ratio (Gliding for Range or Maximum Distance Glide). The airspeed for the Maximum Distance Glide is usually given in the Airplane Flight Manual. For single engine, fixed gear airplanes, it is approximately 1.3 times the power off stalling speed.

If the pilot attempts to glide at an angle of attack either greater or less than that which gives the best L/D ratio, then in each case the path of descent will be steeper in still air.

Another factor which affects the glide path is, of course, the wind. A strong headwind or tail wind will tend to steepen or flatten the glide as the case may be.

When gliding into a fairly strong wind, greater distance may be covered over the ground if the nose of the airplane is kept somewhat lower than the attitude for best L/D ratio. For one thing, the increase in airspeed will yield an increase in ground speed which, in this case and contrary to gliding in still air or very light winds, will yield a shallower glide path. Secondly, by gliding at a slightly higher airspeed, the airplane will complete its glide in less time, having been subjected to the headwind for a shorter duration.

Power Approach.

The technique of gliding should be mastered by the student pilot in case at some time during his career he should have to make a forced landing with engine failure. The normal method of descent for landing, however, is the **Power Approach.** By applying power, the glide path may be flattened and the rate of descent more accurately controlled. Power approaches are advisable for light airplanes when landing in high winds or in gusty air conditions. Power approaches and power stall landings are often used when making landings on soft snow, sand or mud and by seaplanes landing on glassy water. To make a power approach: (i) Reduce power. (ii) Allow the airplane to slow to approach speed. (iii) Adjust to desired angle of descent. (iv) Maintain constant airspeed and regulate rate of descent by manipulation of power. The normally recommended airspeed for power-on approaches to short field landings is 1.3 times the power-off stalling speed.

TURNS

To make an airplane turn, the wings are rolled away from the normal horizontal position of level flight. The lift force, which always acts at 90° to the wing span, is, in a turn, inclined away from the vertical. Therefore, the vertical forces of lift and weight are no longer in balance, that is, are no longer in equilibrium. The airplane will descend unless the angle of attack is increased to produce more lift.

In a turn, the lift force has two components: one acting vertically and one acting horizontally. The vertical component opposes weight, while the horizontal component makes the airplane turn. This horizontal force is known as **Centripetal Force** and it counteracts the **Centrifugal Force** that, in a turn, tends to pull the airplane to the outside of the turn.

In Fig. 33, OW represents the weight of the airplane. The vertical component OA balances the weight of the airplane. OC represents the Centripetal Force necessary to counteract Centrifugal Force. OL is the resultant total lift factor.

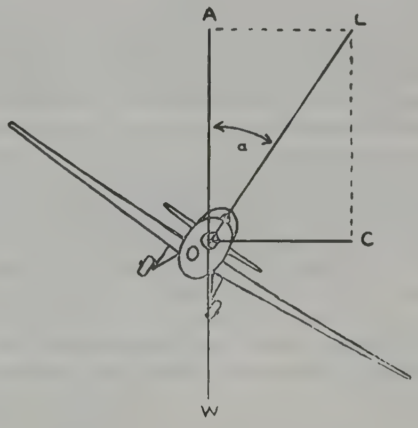


Fig. 33. Forces acting in a Turn.

The steeper the angle of bank, the more total lift is required to produce a level turn. The vertical component of the lift force must remain sufficient to compensate for weight. As the angle of bank increases, the total lift must be increased to provide sufficient Centripetal Force to overcome the increasing Centrifugal Force. This is accomplished by increasing the angle of attack by back pressure on the control column.

The steeper the angle of bank (for any given airspeed): (a) The *greater* the *rate* of turn. (b) The *less* the *radius* of turn. (c) The *higher* the *stalling speed.* (d) The *greater* the *loading.*

The higher the airspeed (for any given angle of bank): (a) The *slower* the *rate* of turn. (b) The *larger* the *radius* of turn.

Load Factors in Turns

In straight and level flight, an airplane has a load factor of 1, or 1 g. Turns increase the load factor. The steeper the angle of bank, the greater the load factor. A 60° turn produces a load factor of 2, making the effective weight of an airplane twice its normal weight. If an airplane weighs 2500 pounds in level flight, in a 60° turn, it will have an equivalent weight of 5000 pounds. A very steep turn may impose an increase in the loading as high as ten times the normal load. With some types of light airplanes, a bank of 80° or over can lead to a possibility of structural failure.

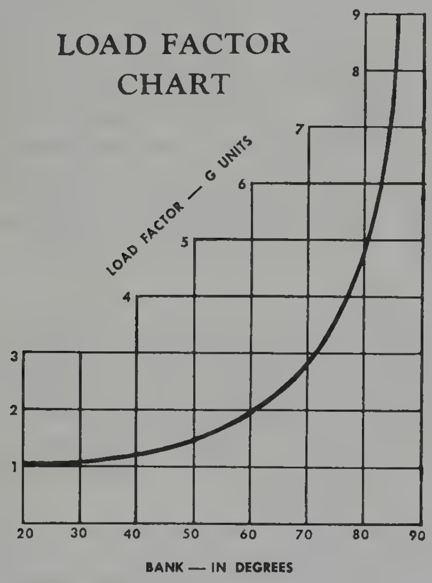


Fig. 34. Load Factors in Turns.

STALL

The airfoil stalls when the angle of attack is increased to the point where the steady streamlined flow of air is unable to follow the upper camber of the airfoil. The airflow separates from the wing, or "burbles", with the result that not enough lift is produced to sustain flight. This is called the "stall condition".

The point at which the airflow pulls away from the wing is called the **Separation Point.**

At high cruising speeds, the positive angle of attack is very low and the separation point is near the trailing edge of the wing. At slower speeds, the angle of attack must be increased to maintain a constant altitude and the separation point moves forward. When the angle of attack is increased to the point that the separation point moves forward far enough to exceed the design factor of the wing, the wing must stall. The stalling angle is commonly in the vicinity of 20° but varies with the shape of the airfoil.

The high lift airfoil, with a curved upper surface and a nearly flat bottom surface, generally stalls at a lower speed and a greater angle of attack than the more efficient high speed symmetrical or laminar flow airfoils used for modern general aviation airplanes.

An airplane properly loaded will stall at an **indicated airspeed** somewhere near the stalling speed published in the Airplane Flight Manual. This stalling speed, for all practical purposes, remains the same regardless of altitude.

An airplane will, however, stall at any airspeed if the critical angle of attack is exceeded.

Factors Affecting Stall

Weight: Weight affects the stalling speed of an airplane. Weight added to an airplane requires that it be operated at a higher angle of attack to produce the lift necessary to support that weight. Therefore the critical angle of attack will be reached at a higher airspeed.

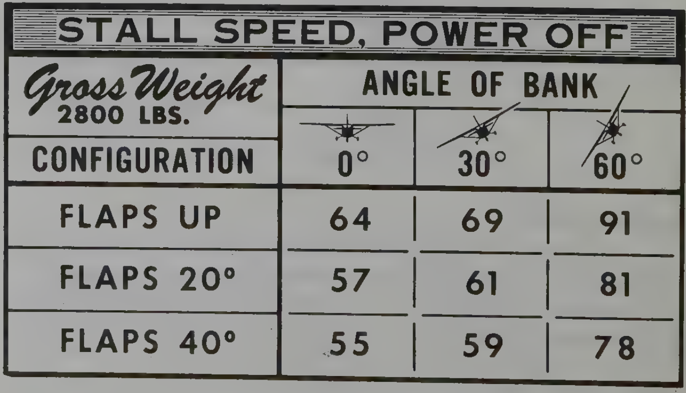
Centre of Gravity: If the weight distribution is such that the C.G. is outside the allowable C.G. limits, the stalling speed as well as stability characteristics will be affected. If the airplane is loaded with the weight too far forward, it will stall at a higher airspeed than normal. If the load is too far aft (and the C.G. therefore aft of the allowable C.G. range), the airplane will stall at a lower airspeed. Associated problems, such as decreased longitudinal stability, violent stall characteristics and poor stall recovery make improper loading a very poor policy.

Turbulence: Turbulence affects stall speed. An upward vertical gust causes an abrupt increase in angle of attack because of the change in direction of the air relative to the wing and could result in a stall if the airspeed of the airplane is at the same time relatively low.

Turns: As the angle of bank increases, the amount of lift required to sustain level flight also increases because of the increasing load factor that is integral to the action of banking an airplane. To increase lift, the pilot must increase the angle of attack of the airfoils. Therefore, in a turn, the stall angle is reached at a higher airspeed than in level flight. Most Airplane Flight Manuals have a chart similar to that in Fig. 35. that depicts the stalling speed at various angles of bank. There is, however, a fairly simple formula for determining stalling speed: normal stalling speed times the square root of the load factor being imposed. Typical load factor values and their square roots are shown in the following table:

Degree of Bank	Load Factor	Square Root
15°	1.04	1.02
30°	1.15	1.07
45°	1.41	1.19
60°	2.00	1.41
75°	3.86	1.96

The stalling speed of the airplane to which the chart in Fig. 35 applies is 64 knots. In a 30° banked turn, the stalling speed would be 64 kts x 1.07 (the square root of the load factor of 1.15), or 68.48 knots.



STALL SPEED, POWER OFF

Gross Weight 2800 LBS.	ANGLE OF BANK		
CONFIGURATION	0°	30°	60°
FLAPS UP	64	69	91
FLAPS 20°	57	61	81
FLAPS 40°	55	59	78

Fig. 35. Stall Chart.

Flaps: The use of flaps, by increasing the lift potential of the wing, results in a reduction in stall speed, as indicated in the Stall Chart in Fig. 35.

Snow, Frost and Ice: An accumulation of frost, snow or ice on the wings will cause an increase in the stall speed. Even a small amount of frost, etc. will disrupt the smooth flow of air over the wing, decrease lift and increase the stall speed. It is possible for the stalling speed to be increased to such a degree that the airplane cannot reach a sufficient speed to achieve take-off, or if having achieved take-off, to maintain flight. Frost, snow and ice should always be removed before take-off.

Stall Warning Devices

Many light airplanes are fitted with a stall warning. This is a device which measures the angle of attack by means, usually, of a small vane extending forward of the leading edge of the wing. When the critical angle of attack is approached, it activates a warning device in the cockpit. This can be a red light, a bell or a buzzer of some sort.

Stall Recovery

Because insufficient lift is being generated by the wings to maintain flight, a stalled airplane starts to lose altitude. To recover from a stall, the pilot can

1. lower the nose to decrease the angle of attack, or
2. apply more power to accelerate the airplane. If, however, the airplane is already under full power when the stall occurs, the only option for recovery from the stall is to lower the nose of the airplane.

Spinning

When a wing is stalled, an increase in the angle of attack will **decrease** lift. If a disturbance causes a stalled airplane to drop one wing, or if rudder is applied to produce a yaw, the downgoing wing will have a greater angle of attack to the relative wind, will receive **less lift** and will tend to drop **more** rapidly (Fig. 36).

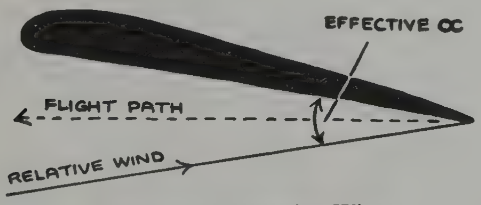


Fig. 36. Downgoing Wing.

The upgoing wing will have a relative downward wind, hence a **decreased** angle of attack, therefore, **increased** lift, and will rise more rapidly (Fig. 37).

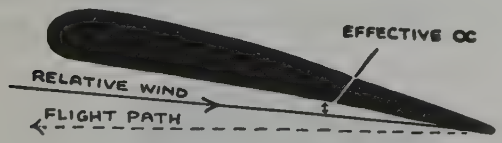


Fig. 37. Upgoing Wing.

The effect is to **accelerate** the rolling moment in the direction in which it first started. This is **spinning.**

Any attempt to correct a spin with aileron will only aggravate the roll. If the aileron on the downgoing wing is moved downward to bring the wing up, it will meet the airflow at a high angle of attack and will therefore become more stalled than the wing itself. The upgoing aileron, on the other hand, will be unstalled and will have increased lift.

To recover from a spin, the pilot should **correct roll by use of rudder,** not aileron.

AIRSPEED LIMITATIONS

Loads greater than the weight of the airplane are produced by certain maneuvers and by gust conditions. In straight and level flight, the lift is equal to the weight. But an increase in speed will produce an increase in lift, which, in turn, will cause the airplane to climb. In order to maintain level flight when the airspeed is increased, the angle of attack must be reduced. An airplane flying in turbulent air may be subjected to severe vertical gusts which will, in effect, change the angle of attack on the wings. If the airplane is flying *too slow,* the increased angle of attack may be great enough to cause the wings to stall. If, on the other hand, the airplane is flying *too fast,* the vertical acceleration may impose a load factor on the wings in excess of what they are strong enough to bear. For this reason, certain speeds are established by the manufacturer of each particular airplane and specified in the Flight Manual.

THE NEVER EXCEED, or MAXIMUM PERMISSABLE DIVE SPEED (V_{NE}). The maximum speed at which the airplane can be safely operated in smooth air. **A higher speed may result in structural failure, flutter, or loss of control.** (If you ever find yourself over the Never Exceed Speed inadvertently, throttle back and execute pull-outs with slow and firm pressure on the controls.)

MAXIMUM STRUCTURAL CRUISE, or NORMAL OPERATING LIMIT SPEED (V_{NO}). This is the cruise speed for which the airplane was designed and is the maximum safe speed at which the airplane should be operated in the normal category. **Warning: Do not EVER exceed this speed intentionally, even during descent, because of the possibility of unexpected gust loads.** The speed range between V_{NO} and V_{NE} (erroneously described as the "Caution" Range) should never be entered deliberately during normal operation.

MANEUVERING SPEED (V_A). The maximum speed at which the flight controls can be fully deflected without damage to the airplane structure. This speed is used for abrupt maneuvers or when flying in very rough air or in severe turbulence. At this speed, it is impossible for gusts to produce dangerous load factors. This is the speed least likely to permit structural damage to the airplane and yet allow a sufficient margin of safety above the stalling speed in gusty air. **Maneuvers which involve an approach to a stall, or full use of rudder or aileron control, should never be attempted above this speed.**

Note: Pilots flying high speed jets at high altitude may elect to maintain somewhat higher speeds when penetrating turbulent air. This is because the risk of an inadvertent stall (due to severe gust loads at high altitude) may present as great a hazard as the risk of structural strain. (Bear in mind when you get in the supersonic league that you can stall an airplane at almost any speed if you subject it to a sufficient number of "g's".)

MAX. FLAPS DOWN SPEED (V_{FE}). The maximum speed at which the airplane may be flown with the flaps lowered. A speed in excess of this value may lead to a structural failure of the flaps.

CATEGORIES — NORMAL AND UTILITY

Official Aircraft Specifications, which federal licensing authorities insist must be published before civil airplanes can be approved for certification, include operational information on speed and load limitations depending on how the airplane is to be operated. This information is also to be found in the manufacturer's manual. The information is usually published for two categories, **Normal and Utility.** A third category, **Aerobatic,** is published for certain airplanes.

NORMAL CATEGORY

Maximum gross weight operations are permitted but certain maneuvers, such as spins, steep turns, etc., are prohibited.

UTILITY CATEGORY

Certain specified maneuvers may be performed but they must be carried out at reduced weight, narrower C.G. range and reduced airspeed. Baggage compartments and rear seats usually must be empty. When operated in the utility category, the following maneuvers are usually permitted: chandelles, lazy eights, steep turns, spins and stalls. The utility category is solely for the purpose of instructing and training pilots in certain flight maneuvers.

These operating limitations are set as a result of wing loading and C.G. considerations.

Positive limit load factors for the normal category are 3.8 times the gross weight. The reduced gross weight of the utility category permits a limit load factor of 4.4 times the gross weight. When operating in the utility category, higher g forces can be imposed on the airframe. Because the weight is less than maximum gross weight, the ultimate strength factor of the airframe will not be exceeded.

The negative limit load factors for both normal and utility categories are approximately — 1.52 and — 1.76 respectively.

AEROBATIC CATEGORY

In the **aerobatic** category, positive limit load is 6.0 times the gross weight and the negative limit load is — 3.0.

MACH NUMBER

The **Mach Number** (pronounced "Mock") is the ratio of the speed of a body to the speed of sound in the air surrounding the body. (The **Speed of Sound** is proportional to the square root of the absolute temperature. This variation of the speed of sound with temperature accounts for the fact that at cold Arctic temperatures the speed of sound could be about 660 mph while at warm tropical temperatures it might be over 760 mph.) An airplane flying at a Mach Number of .85 would be travelling at 85% of the speed of sound.

The Mach Number is found by dividing the airspeed by the speed of sound at the particular altitude and temperature existing at the time of flight.

A Mach Number of 1 equals 761 mph at sea level. At 40,000 feet, a Mach Number of 1 equals 663 mph.

FLIGHT INSTRUMENTS

An understanding of the various flight instruments and the way they work is essential to the pilot. With a basic knowledge of their characteristics and especially their limitations, a pilot is better able to interpret the information displayed on the instruments during various flight conditions.

PITOT STATIC INSTRUMENTS

Instruments connected to the pitot static system include the airspeed indicator, the altimeter and the vertical speed indicator. The system includes a pitot tube and a static pressure tube.

The pitot tube is usually located on the leading edge of the wing where it is clear of the slipstream and in a position to be as free as possible of air disturbance. The opening of the tube faces the line of flight. When the airplane is in flight, the atmospheric pressure in this tube is increased by dynamic pressure due to the forward motion of the airplane through the air. The airspeed indicator is the only instrument affected by the pitot tube.

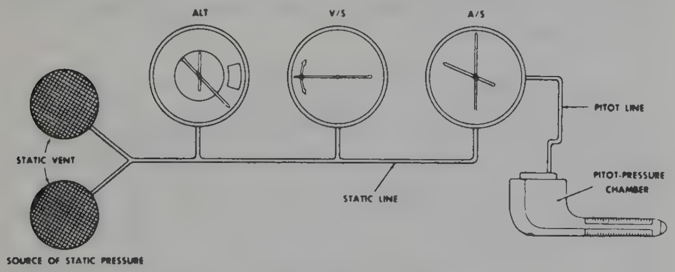


Fig. 37.1. Pitot Static System.

The airspeed indicator, the altimeter and the vertical speed indicator are all connected to the static pressure tube through which they are vented to allow air pressure inside their cases to equalize with the outside barometric pressure as the airplane gains or loses altitude. The ports, or vents, of the static tube are usually located on the sides of the fuselage where they will not be affected by turbulence or by ram air pressures.

One of the problems of the pitot static system is that the openings are susceptible to the accumulation of dirt, water and ice. Blocked or partially blocked openings will cause inaccurate readings of the instruments. For this reason, the pitot tube and static vent openings should always be checked before a flight to see that they are clear. On many modern airplanes, the pitot tube is electrically heated to prevent the buildup of ice during flight.

THE ALTIMETER

The Altimeter is a special form of aneroid barometer (a barometer without liquid) which measures the pressure of the atmosphere. It is connected to the static pressure tube through an outlet in the back of the case. This outlet serves as a vent to allow static atmospheric pressure to move into and out of the altimeter case as the airplane climbs or descends.

The atmospheric pressure at any point is due to the **weight** of the overlying air above, which **decreases** as the height above sea level **increases.** Hence, the instrument can be calibrated to read in terms of height. Under **Standard Air Conditions** of 15°C the weight of a column of air — one square inch in area — is 14.7 lb. at sea level. It exerts a pressure of 14.7 lb. per sq. in. This pressure is recorded on a barometer as 29.92 inches of mercury and by an altimeter as 0 feet. At 10,000 feet the weight of one square inch air column has decreased to 10.11 lb., the corresponding barometric pressure to 20.58 inches, and the altimeter records 10,000 feet. Note that as the altitude **increases,** the barometric pressure **decreases.**

The basic components of the altimeter are a stack of aneroid capsules located inside the case. These capsules are sealed and contain standard sea level pressure. Atmospheric pressure admitted to the case through the static pressure system causes these capsules to expand and contract. The expansion and contraction of these capsules transmits motion directly to gears and levers which rotate hands on the face of the altimeter. A large hand records altitude changes in hundreds of feet; a smaller hand records altitude in thousands of feet; and a third still smaller hand records altitude in units of ten thousand feet. The altimeter depicted in Fig. 38 is reading 10,400 feet.

As the airplane climbs, the outside barometric pressure decreases and air moves out of the case through the static vent system. As a result, the aneroid capsules expand, causing an increased altitude reading. As the airplane descends, air moves into the altimeter case and the capsules contract, causing a decreased altitude reading.

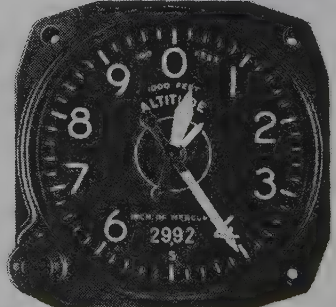


Fig. 38. Sensitive Altimeter.

Altimeter Errors

1. **Pressure.** The heights at which airplanes are required to

fly for air navigation purposes are *Indicated Heights Above Sea Level.* Since the barometric pressure varies from place to place, an altimeter set to indicate height above sea level at the point of departure may give an erroneous indication after the airplane has flown some distance towards its destination. To correct for this, altimeters are fitted with a **Barometric Scale,** calibrated in inches of mercury.

The **Altimeter Setting,** which is given in inches, may be obtained from towers and aeradio stations in any particular locality over which the airplane is operating. In Fig. 38, the Altimeter Setting is 29.92 inches.

It is important, on a long cross country flight, for a pilot to get updated altimeter settings and regularly reset the altimeter. It is true that, if the airplane is operating well above the earth's surface, knowledge of the exact distance above the ground is of little immediate importance. However, if the airplane is operating at no great height above the ground or above the highest ground enroute, especially in conditions of poor visibility or when on instruments, knowledge of the "actual" separation between the airplane and the ground is of vital importance. Take, for example, a situation in which a flight altitude of 6000 feet has been selected to clear a 4800 foot mountain ridge that lies across the course near the destination. The altimeter setting at the airport of departure was 29.80". The altimeter setting at the destination airport, however, is only 29.20". If the pilot does not reset his altimeter, the airplane will clear the mountain ridge by only 600 feet instead of the 1200 feet expected.

An altimeter setting that is too high will give an altimeter reading that is too high. Each .10" Hg that is added to the altimeter setting will increase the Indicated Altitude recorded by the altimeter by approximately 100 feet. An altimeter setting that is too low will give an altimeter reading that is too low. Therefore, when an airplane is flying from an area of high pressure into an area of low pressure (or from warm air into colder air) if a corrected altimeter setting has not been obtained by radio, the altimeter will read high. *"From high to low — watch out below"*

In the northern hemisphere a drift to the right or starboard, indicates that an airplane is flying towards an area of low pressure. A glance at the wind circulation around a low pressure area — see Fig. 9 in Chapter **Meteorology** — will indicate why this is so. Continued drift to starboard over a long period should act as a warning that an uncorrected altimeter may be reading high.

ALTIMETER SETTING REGION: When the altimeter setting is set on the Barometric Scale, the altimeter will register the **Indicated Height Above Sea Level.** When you land at an airport from which the altimeter setting was obtained by radio, your altimeter will record the **altitude of the field above sea level.**

The altitude at which an airplane flies when using Indicated Height Above Mean Sea Level as its reference is known as **Cruising Altitude.**

In Canada, the area in which the Indicated Height Above Sea Level is used is known as the Altimeter Setting Region. It is defined in ANO V, No. 16.

When taking off within the Altimeter Setting Region, or approaching to land, the altimeter should be set to the current altimeter setting of the field. If this is not obtainable, to the altitude of the field above sea level. During flight, the altimeter should be progressively re-set to the altimeter setting of the nearest station along the route of flight.

STANDARD PRESSURE REGION: Over trans-oceanic routes and certain continental areas, altimeter settings are not available. Flights over these areas are flown at Pressure Altitude (defined below). Because the altimeter is less reliable at high altitudes, flights above 18,000 ft. MSL are also flown at Pressure Altitude.

Pressure Altitude is the height above sea level corresponding to a given barometric pressure under Standard Air conditions. When the Barometric Scale is set to read 29.92, the height recorded by the altimeter is Pressure Altitude.

In this case, the altitude at which the airplane is flying is referred to as the **Flight Level.** In reporting the Flight Level, the last two digits of the altitude are omitted. e.g. An airplane flying at a Pressure Altitude of 15,000 ft. would report its height as "Flight Level 150 (FL 150)".

In Canada, the region in which the altimeter setting of 29.92" Hg. (1013.2 millibars) is used is known as the Standard Pressure Region. It is defined in ANO V, No. 16.

When taking off or approaching to land within the Standard Pressure Region, the altimeter should be set to the **current altimeter setting of the field.** If this is not obtainable, to the altitude of the field above sea level. Immediately upon reaching cruising altitude, the altimeter should be re-set to 29.92"Hg.

When flying out of the Standard Pressure Region into the Altimeter Setting Region, or vice versa, the altimeter should be adjusted to the setting appropriate to the area in which the airplane is being flown. See also **"Cruising Altitudes".**

Field Level Pressure is the **actual** barometric pressure (not corrected to sea level) at any particular airport. If a pilot obtains the Field Level Pressure by radio from an airport he is approaching, and sets it on his Barometric Scale, his altimeter will register 0 feet when he lands.

2. Temperature. Due to continual heating and cooling, the atmosphere at any given point is seldom at the temperature of Standard Air. Cooling causes air to sink. The air above the point where the cooling occurred will therefore weigh less, and the altimeter — designed to convert standard barometric pressure to feet — will indicate too high.

Changes in temperature may cause the altimeter to register an Indicated Altitude as much as 2500 feet above or below the True Altitude.

If the actual temperature of the air column in which the airplane is flying is **colder** than Standard Air, the True Altitude of the airplane above sea level will be **lower** than the Indicated Altitude. If the actual temperature is **warmer** than Standard Air, the True Altitude will be **higher.**

Since all altimeters in the same area are equally affected by Temperature Error, air traffic regulations require you to fly **only at Indicated Altitude.** However, it is important, particularly in mountainous country, for a pilot to be able to calculate his True Altitude above sea level.

All computers currently in use are fitted with a sliding scale for correcting temperature error and converting Indicated Altitude to True Altitude. However, the correction is based on the Pressure Altitude rather than the Indicated Altitude. To find the former at any time simply set the Barometric Scale to 29.92 and the altimeter will record the Pressure Altitude.

Density Altitude. Barometric pressure and temperature both affect density. Density is an important factor in the take-off performance of modern airplanes. Low densities reduce engine thrust and aerodynamic lift. **Density Altitude** is important in calculating the safe fuel and payload permissible for take-off. Density Altitude can be determined when the **Pressure Altitude** (at the airport) and the **Temperature** are known. Most modern circular slide rules are calibrated to compute Density Altitude. However, if a computer is not available, the approximate Density Altitude may be found by the following simple formula:

Density Altitude = Pressure Altitude + [120 X (Actual Temperature — Standard Temperature)].

Note: The above method will prove accurate to within 200-400 feet.

Example:

Field Elevation at airport	1000 feet
Pressure Altitude at airport	2000 feet
Actual Temperature	25°C.
Standard Temperature	15°C.

Hence: Density Altitude = 2000 + (120 x (25° — 15°) = 3200 feet.

3. **Mountain Effect.** Winds which are deflected around large single mountain peaks or through valleys of mountain ranges

tend to increase speed which results in a local decrease in pressure (Bernouli's Principle). A pressure altimeter in such an airflow will give an altitude reading that is too high.

Winds blowing over a mountain range often create a phenomenon that is known as the mountain wave. The effect of a mountain wave often extends as far as 100 miles downwind of the mountains and up to altitudes much above the actual elevation of the mountain ridge. Within the mountain wave, downdrafts are usually very intense and as a result of the increased wind speed, there is a local drop in pressure. Altimeters may read as much as 3000 feet too high in severe mountain wave conditions.

THE AIRSPEED INDICATOR

The Airspeed Indicator tells the pilot the speed at which he is travelling through the air (not over the ground). The dial is calibrated in miles per hour, or knots (Fig. 39).

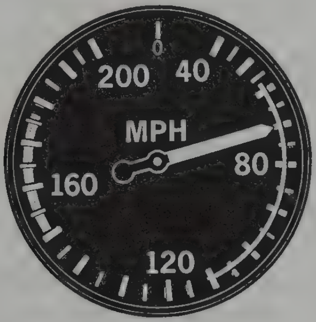


Fig. 39. Airspeed Indicator.

The Airspeed Indicator is connected to both the pitot tube and the static pressure tube. To give a reading of speed through the air, the instrument measures the difference between the impact and the static air pressure, that is, the pressure in the pitot tube and the pressure in the static system. When the airplane is standing on the ground, the two pressures are equal. In motion, the pressure in the pitot tube becomes greater than that in the static pressure tube.

The two tubes lead to opposite sides of a diaphragm installed in the case of the instrument (Fig. 40).

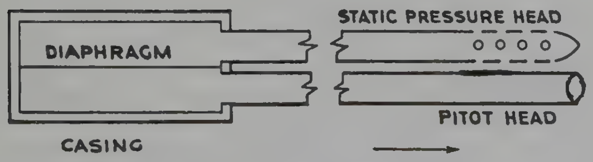


Fig. 40. Principle of the Airspeed Indicator.

The difference between the two tube pressures causes a movement of the diaphragm. This movement is transmitted through a system of links and levers to a hand, which rotates around a dial calibrated in miles per hour. This is a very simple type of Airspeed Indicator.

A more complicated type incorporates a capsule which is a thin corrugated metal expansion box. The pitot tube leads to the interior of this box and the static pressure tube to the inside of the instrument case. The changes in dynamic pressure inside the box cause it to expand or contract. This movement, through a system of linkage, rotates the hand on the face of the dial.

Airspeed Indicator Markings

Colour coded markings are used on the Airspeed Indicator to indicate safe operating ranges and operating limits.

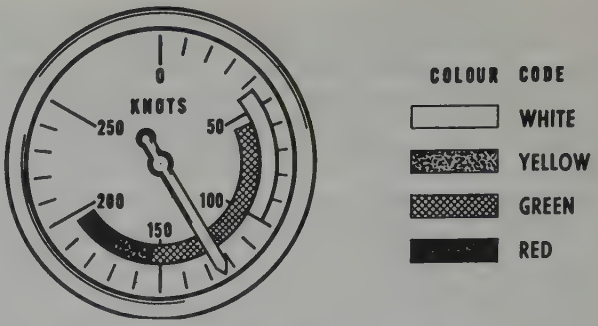


Fig. 41. Markings on Instruments.

1. **Red.** A red line is placed at the Never Exceed Speed (VNE). This is the maximum speed at which the airplane can be operated.

2. **Yellow.** A yellow arc indicates the "caution speed" range. The lowest limit of the yellow arc is the Maximum Structural Cruising Speed (VNO). The airplane should be operated in the "caution speed" range only in smooth air. However, since it is impossible to guarantee that turbulence will not be encountered and that the air will be smooth, the airplane should not be operated intentionally in this range.

3. **Green.** A green arc indicates the normal operating range. The lower limit of the green arc is the Power Off Stalling Speed with flaps and gear up (VSL). The upper limit of the green arc is VNO (the maximum cruising speed for normal operation).

4. **White.** A white arc depicts the speed range in which fully extended flaps may be used. The lower limit of the white arc is the Power Off Stalling Speed with flaps and gear down (VSO). The upper limit on the white arc is the Maximum Flaps Down Speed (VFE).

On the Airspeed Indicator depicted in Fig. 41, VSO is 43 knots, VFE is 100 knots, VSL is 55 knots, VNO is 154 knots and VNE is 195 knots.

Manoeuvring Speed is not marked on the face of the Indicator.

Airspeed Indicator Errors

The Airspeed Indicator is affected by several errors for which correction must be made. These are:

1. **Density:** The density of the air depends on atmospheric pressure and temperature. These are variable factors. Consequently a standard value for density has to be assumed in order that the Airspeed Indicator may be calibrated.

The standard for calibrating Airspeed Indicators is normal sea level pressure, 29.92 inches of mercury, at a temperature of 15°C.

A rough correction may be made by adding 2% to the Indicated Airspeed for every 1,000 ft. of Pressure Altitude.

Example: Indicated Airspeed at 10,000 ft. — 130 knots.

Correction: 10 X 2% = 20%

20% of 130 kts. = 26 kts.

True Airspeed = 130 + 26 = 156 kts.

More accurate corrections, allowing for the actual temperature and pressure, can be obtained with the Dalton Computer or other suitable disk type computers.

2. **Position Error.** This is due to eddies set up in the neighborhood of the wings, struts, etc. and the angle of the head, and is reduced by placing the pitot tube as far ahead of the leading edge of the wing as is practicable. Position Error remaining is tabulated on a cockpit calibration card, or in tables in the Flight Manual. See Fig. 42.

3. **Lag:** This is a mechanical error due to the friction of the working parts of the instrument.

4. **Icing:** Ice formation, blocking the opening of the pitot and/or static pressure tubes, has been a source of considerable trouble with Airspeed Indicators in the past. This has been large-

AIRSPEED CORRECTION TABLE

FLAPS UP	IAS	60	80	100	120	140	160	180	—
	CAS	68	83	100	118	137	156	175	—
*FLAPS DOWN 20°-40°	IAS	40	50	60	70	80	90	100	110
	CAS	58	63	68	75	84	92	101	110

*Maximum Flap Speed 110 MPH, CAS

Fig. 42. Airspeed Correction Table.

ly eliminated in present day instruments by the adoption of electrically heated pitot heads.

The question, of course, is when should pitot heat be used. Generally, in summer, it is not necessary to be concerned about moisture or ice in the pressure system. In spring, fall and winter, when outside temperatures drop and the moisture content of the air increases, the situation can be more critical. Any moisture, either in solid or liquid form, may cause an erroneous reading of the Airspeed Indicator. An accumulation of ice that completely blocks the pitot tube opening will cause a complete loss of airspeed indication. Even while the airplane is parked, if the pitot tube is not covered, rain, snow or frost may collect in the system and obstruct the free passage of air. For this reason, it is advisable to use pitot heat whenever the airplane is being operated in sensitive temperature or moisture conditions. As a rule of thumb, 10°C might be selected as the critical temperature. Turn the pitot heat on just prior to take-off and turn it off after landing since extended use of the pitot heat on the ground may cause the heater element to burn out.

5. Water: Water in the system can cause very erratic airspeed indications. The errors may be high or low, depending on whether the water is in the dynamic or static tubes. Sufficient water in the dynamic tube to block it off, for instance, would convert the Airspeed Indicator into an Altimeter — and the indicated airspeed would vary with changes in height. The pitot head should be covered when an airplane is standing in the open to prevent water getting into the system.

Airspeed Definitions

Indicated Airspeed (IAS) is the uncorrected speed read from the airspeed dial. It is the measurement of the difference between impact pressure and atmospheric pressure in the pitot-static system.

Calibrated Airspeed (CAS) is indicated airspeed corrected for instrument error and installation error in the pitot-static system. As the airplane flight attitude or configuration is changed, the airflow in the vicinity of the static inlets may introduce impact pressure into the static source, which results in erroneous airspeed indications. The pitot section is subject to error at high angles of attack, since the impact pressure entering the system is reduced, when the pitot tube is not parallel to the relative wind. Performance data in airplane flight manuals is normally based on calibrated airspeed.

Equivalent Airspeed (EAS) is calibrated airspeed corrected for compressibility factor. This value is very significant to pilots of high speed aircraft, but relatively unimportant to pilots operating at speeds below 250 knots at altitudes below 10,000 feet.

True Airspeed (TAS) is calibrated (or equivalent airspeed) corrected for air density error. TAS is the actual speed of the airplane through the air mass. (See "**Density**" above.)

THE VERTICAL SPEED INDICATOR

The Vertical Speed (Vertical Velocity, or Rate of Climb) Indicator shows the rate, in feet per minute, at which the airplane is ascending or descending. The principle on which it operates is the change in barometric pressure which occurs with any change in height. This instrument is contained in a sealed case and is also connected to the static air pressure system.

Atmospheric pressure is led from the static tube directly into a corrugated expansion box, or diaphragm, contained within the case of the instrument. From there air is permitted to "leak" at a relatively slow rate through a capillary tube into the case of the instrument. The difference between the quick change in pressure which occurs within the diaphragm and the relatively slow rate at which this pressure is equalized within the case, causes the box to expand or contract. This movement is amplified and transmitted by linkage to the pointer on the dial of the instrument.

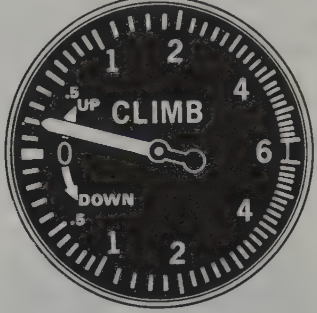


Fig. 43. Vertical Speed Indicator.

When the airplane loses altitude, pressure within the diaphragm increases almost immediately, while pressure within the case changes slowly. The diaphragm therefore expands, and the pointer indicates DOWN in feet per min.

When the airplane gains altitude, the process is reversed, and the pointer indicates UP.

When the airplane remains level, the pressures equalize, and the pointer indicates O.

Note that the Vertical Speed Indicator registers the rate of climb or descent, not the attitude of the airplane. An airplane may gain height in a vertical up-current of air when it is flying perfectly level. The Vertical Speed Indicator should be closely coordinated with the Airspeed Indicator. Corrections for altitude gained or lost in cruising flight should be made by nosing the airplane up or down— by use of the elevators. Intentional change in altitude should be made by increasing or decreasing power at a given airspeed — by use of the throttle.

Lag

A change in altitude must occur before the Vertical Speed Indicator can indicate such a change. Although the indicator will show quite quickly a climbing or descending trend, there is a lag of from 6 to 9 seconds before it will indicate the correct rate of climb or descent. The instrument too will still indicate a vertical speed for a short time after the airplane has leveled off. If pitch changes are made slowly, the lag is minimal and the instrument will give a fairly accurate representation of the vertical speed at any given moment. If the pitch changes, however, are large and rapid, the amount of lag in the instrument will be sizeable.

Instantaneous Vertical Speed Indicators are available that do not have lag and are therefore very accurate. They operate on a more complicated arrangement of pistons and cylinders that give an almost instantaneous indication of change in vertical speed.

THE RADAR ALTIMETER

The Radar Altimeter (also known as the Absolute Altimeter or the Radio Altimeter) indicates the actual height of the airplane above the earth, or above any object on the earth over which the airplane is passing. The principle is extremely simple. A radio transmitter in the airplane sends a signal towards the earth whose frequency changes at a definite rate with respect to time. This signal is reflected by the earth and returns as an **Echo** after a time interval equal to twice the height divided by the velocity of the signal. During this interval, the frequency of the transmitter has changed and now differs from that of the echo by the rate of change of frequency X the time of transit. The reflected wave is combined with some of the outgoing wave in the plane receiver, and the difference, or "beat" frequency, is measured by a Frequency Meter. Since the reading of the meter is that of the "beat" frequency, it is proportional to the time delay of the echo — hence to the **height** — and can thus be calibrated in feet.

The Radar Altimeter performs an important function in Pressure Pattern Flying. By comparing the readings of the radar altimeter and an altimeter set to pressure altitude, current changes in the atmospheric pressure at flight level may be determined. This provides in-flight information on the changing locations of pressure systems and on the airplane drift angle. (See **"Pressure Pattern Flying"**).

Radar Altimeters are also used extensively by airplanes engaged in specialized types of flying, such as aerial survey, agriculture, etc., to maintain positive altitude above the ground regardless of rolling terrain, hills or valleys. They are also used in airplanes flying on IFR and night VFR flights. By displaying to the pilot exact information about his height above the ground, they are an additional safety instrument when landing and are of immense value from that viewpoint.

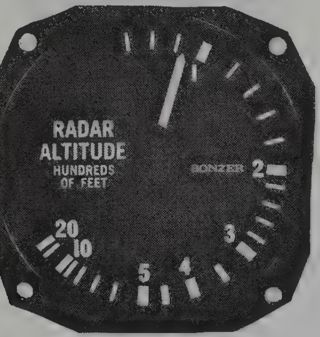


Fig. 44. Bonzer Radar Altimeter.

GYRO INSTRUMENTS

Gyro instruments have made the art of piloting an airplane more precise. They are very useful in VFR Flight. In Instrument Flight, they are invaluable. In most general aviation airplanes, there are three gyro instruments; the Directional Gyro or Heading Indicator, the Artificial Horizon or Attitude Indicator, and the Turn and Slip Indicator.

THE GYROSCOPE

The Gyroscope is a rotor, or spinning wheel, rotating at high speed in a universal mounting, called a gimbal, (Fig. 45) so its axle can be pointed in any direction.

The peculiar actions of a gyroscope, though they may appear to defy physical laws, actually depend entirely upon Sir Isaac Newton's Laws of Motion.

All of the practical applications of the gyroscope are based upon two fundamental characteristics, namely, Gyroscopic Inertia (or Rigidity in Space) and Precession.

Gyroscopic Inertia is the tendency of any rotating body, if undisturbed, to maintain its plane of rotation. When the rotor in Fig. 45 is spinning about its axis A-B, the direction of this axis will remain fixed in space, regardless of how the base of the gyroscope is moved around it.

Precession is the tendency of a rotating body, if a force is applied to it, to turn about an axis at right angles to the axis about which the force was applied. The following is a simple illustration: Imagine a bicycle wheel spinning rapidly on a broomhandle which is held horizontally in your hands. Attempt to push either end forward and one end will automatically raise in your hand while the other will drop. A push applied in the direction of the arrow at G (Fig. 45) would cause the rotor in its supporting ring to tend to rotate around the axis C-D.

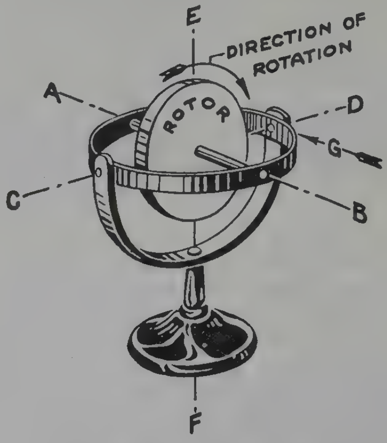


Fig. 45. The Gyroscope.

The wheel, or rotor, is free to revolve in its supporting ring about the axis A-B. The supporting ring is free to revolve in the outer ring about the axis C-D, at right angles to the rotation axis of the rotor. The outer ring is free to revolve about the vertical axis E-F on the pivot bearing at F.

POWER SOURCES FOR GYRO INSTRUMENTS

The gyro instruments require a source of power to drive their gyros. This power is supplied either by the electrical system of the airplane or by a vacuum system that functions by means of an engine-driven pump or a venturi.

Engine Driven Vacuum System

Air pressure differential is the principle on which the vacuum driven gyro instruments operate. A vacuum pump run by the airplane engine creates a partial vacuum in the system. A filtered air inlet upstream of the gyros allows air to rush into the system causing the gyro wheels to spin.

The gyro instruments require a suction of from 4 to 6 inches of mercury to operate. (Various manufacturers require differing vacuum settings for their particular instruments.) A vacuum pressure gauge, mounted on the instrument panel, indicates the amount of suction being generated in the system. The gauge indicates the relative difference between the outside air pressure and the air in the vacuum system. If there is not enough suction, the gyros will not spin fast enough for reliable operation. If there is too much suction, excessive wear of the gyro bearings will result from the gyros spinning too quickly.

The advantage of the engine driven vacuum system is that it starts operating as soon as the engine starts. On the other hand, in the event of engine failure, all power to the gyro instruments will be lost.

Venturi Driven Vacuum System

A venturi is used in place of a vacuum pump on many light airplanes. It has the advantage of being inexpensive to install and simple to operate. However, its efficiency is dependent on the airspeed of the airplane and the venturi tubes themselves cause some aerodynamic drag.

The venturi tubes (there may be one or more) are usually mounted on the side of the airplane in a position to be in the airflow from the propeller. As the airflow enters the constriction of the venturi, the velocity of the airflow increases. A low pressure area is created within the venturi that results in a partial vacuum in the line leading from the venturis to the gyro instruments.

Electrically Driven Gyros

Electrically driven gyros were first developed for use in airplanes that flew at very high altitudes where atmospheric pressure was too low to operate a vacuum system. Alternating current from engine driven alternators or generators provides the power to drive the gyros.

Many of the newer electrically operated gyro instruments have the feature that they will not tumble in aerobatic maneuvres.

It is common practice to use a combination of electric and vacuum driven instruments for safety's sake, in case one system fails. Often the DG and the Artificial Horizon operate on the vacuum system while the Turn and Slip is electrically operated. Large airplanes usually have two complete sets of instruments, one driven by a vacuum system, the other by electricity.

THE DIRECTIONAL GYRO

The Directional Gyro (or Direction Indicator) is an instrument designed to indicate the heading of the airplane and to enable the pilot to steer it.

The basic mechanical principle revolves around a Gyro Wheel or Rotor mounted **vertically** and spinning about its horizontal axis at approximately 12,000 rpm.

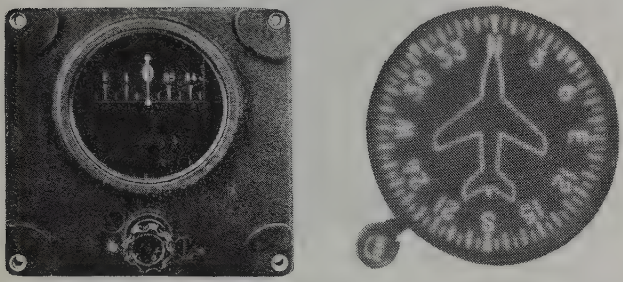


Fig. 46. Directional Gyro.

The spinning gyro wheel is universally mounted in a Gimbal Ring, free to turn about an axis. The Azimuth Card, which the pilot reads through a rectangular window on the face of the instrument (Fig. 46) is mounted on the Gimbal Ring and therefore moves with it.

When spinning, the gyro obeys the fundamental gyroscopic principle of rigidity in space. Thus the Rotor and Gimbal Ring, and the Azimuth Card attached to them **remain fixed, while the airplane moves around them.**

Fig. 46 shows two types of Directional Gyros in common use. In that on the left, the Azimuth Card that is geared to the gyro gimbal is read against the lubber line. In the DG on the right, the compass rose card turns as the airplane turns and the heading is read opposite the "nose of the airplane pointer". As in the case of the Compass, the figures are printed with the "0" left off — "1" for "10", "35" for "350", etc.

Pushing the **Caging Knob** (Fig. 46) **in,** "cages" or locks the gyro system upright. When the Caging Knob is pushed in, turning the knob — by means of a synchronizing gear — enables the Azimuth Card or Compass Rose to be turned to any desired Heading. The Gyro is not, of its own accord, North Seeking.

Pulling the Caging Knob **out** releases the locking mechanism, and leaves the gyro axis horizontal and free to indicate changes in direction.

The Magnetic Compass is afflicted with many vagaries, including northerly turning error, acceleration and deceleration errors.

The Directional Gyro remains constant without swinging or oscillating, and provides a means of accurate steering even in rough air. Precise turns can be made and stopped at any desired heading, as the instrument responds instantly without lag.

From all of which it might appear that the Magnetic Compass has had its day. Such would indeed be the case were it not for the fact that the Directional Gyro has a pet little "gremlin" of its own, and must from time to time be reset — using the Magnetic Compass as a reference!

Precession Error

Frictional forces in the gyro system cause it to **precess.** This precession causes a "creep" or "drift" in the reading on the card, amounting to approximately 3 degrees in 15 minutes.

The gyro is also subject to **Apparent Precession.** *Gyroscopic Inertia* keeps the spinning gyro fixed in space so that — relative to space — it does not move. But the earth rotating underneath it gives it an apparent motion relative to the earth. This causes an *apparent* drift, or precession, which varies with latitude. At the Equator, apparent precession is zero. At the Poles it is 15° per hour.

Precession error, both mechanical and apparent, must be corrected for at regular intervals, say, every 15 minutes, or oftener.

To correct for precession:

(1) Hold the airplane straight and level to insure that the magnetic compass is free from error.

(2) Push the caging knob IN. ("Cage").

(3) Turn the directional gyro card to the correct heading as read off the magnetic compass.

(4) Pull the caging knob OUT. ("Uncage").

Limitations of the Directional Gyro

The gyro requires from 4 to 6 inches of mercury vacuum to operate. It should not be used for take-off until it has run for 5 minutes. This time is required to get up to operating speed. (If the gyro is operated by a venturi tube instead of a vacuum pump, it cannot be used for take-off at all.)

The gyro will not function in climbs, glides or banks exceeding 55 degrees. If these limits are to be exceeded — or during aerobatics — the gyro should be caged.

THE ARTIFICIAL HORIZON

The Artificial Horizon (also called the Gyro Horizon or the Attitude Indicator) provides the pilot with a "mechanical" horizon as a means of reference when the natural horizon cannot be seen because of cloud, fog, rain or other obstructions to visibility.

The natural horizon is represented by a Horizon Bar on the face of the instrument (Fig. 47). The attitude of the aircraft in relation to the horizon is indicated by a Miniature Airplane. A pointer at the top indicates degrees of bank on an Index Scale graduated from 0° to 90° right or left.

In the Artificial Horizon the Gyro Wheel is mounted **horizontally** and spins about its **vertical** axis. It is mounted in a universal gimbal ring system, free about both the pitching and rolling axes of the airplane and is therefore able to remain spinning in a horizontal plane parallel to the true horizon, regardless of the rolling or pitching movements of the airplane around it.

The Gyro Wheel is actuated by suction, as is the Directional Gyro. Jets of air strike the blades of the Rotor, causing it to spin. Pendulous valves and ports attached to the gyro housing assist in keeping its axis vertical.

Two types of Artificial Horizon are in common use. They are depicted in Fig. 47.

The horizon bar is attached by a pivoted arm to the gimbal ring and remains parallel to the natural horizon. The relationship of the miniature airplane to the horizon bar is the same as the relationship of the actual airplane to the actual horizon. When the airplane is flying level, the miniature airplane is lined up level with the horizon bar.

When the airplane noses up, the gyro wheel remains horizontal. A relative down force is exerted on the pivoted arm to which the horizon bar is attached, causing the horizon bar to sink below the miniature airplane.

In the case of a nose down condition the reverse action takes place.

The Artificial Horizon may be thought of and used in either of two ways:

1. Some like to consider it as a window through the instrument panel and through the fog or clouds — in which case the horizon bar is where the natural horizon would be.

2. Others like to fly the miniature airplane with respect to the horizon bar.

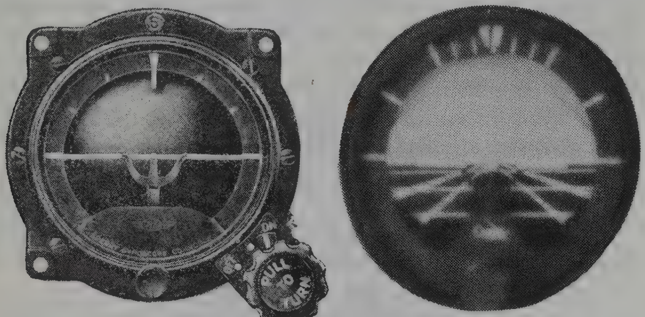


Fig. 47. Artificial Horizon.

When the airplane noses up, the miniature airplane rises above the horizon bar, indicating a nose high condition.

When the airplane noses down, the miniature airplane sinks below the horizon bar, indicating a nose down condition.

When the airplane banks, the miniature airplane banks on the horizon bar and the pointer indicates the degree of bank on the Index Scale.

When it is necessary to fly the airplane slightly nose up or down, according to altitude, power and load, the miniature airplane can be adjusted to match the horizon bar by means of a knob at the bottom of the case.

Limitations of the Artificial Horizon

The gyro requires 4 or more inches of mercury vacuum to operate, and 5 minutes to get up to operational speed.

The Gyro Horizon permits dives or climbs up to 70 degrees and banks up to 90 degrees (vertical). If these limits are to be exceeded — or during aerobatics — the gyro should be caged. The caging knob is shown at the lower right in Fig. 47.

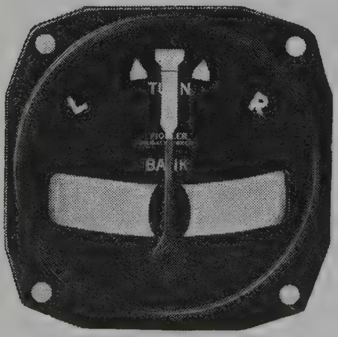


Fig. 48. Pioneer Turn and Slip Indicator.

THE TURN AND SLIP INDICATOR

The Turn and Slip (or Turn and Bank) Indicator combines two instruments in one and is sometimes called the Needle and Ball. The needle indicates the direction and approximate rate of turn of the airplane. The ball indicates the amount of bank in the turn; that is, whether there is any slipping or skidding in the turn.

The ball is controlled by gravity and centrifugal force. It is simply an agate or steel ball in a liquid filled, curved glass tube. In a balanced turn, the ball will remain in the centre as centrifugal force offsets the pull of gravity. In a slip, there is not enough rate of turn for the amount of bank. The centrifugal force will be weak and this imbalance will be shown by the ball falling down toward the inside of the turn. In a skid, the rate of turn is too high for the amount of bank. The centrifugal force is too strong and this imbalance is indicated by the ball sliding toward the outside of the turn.

The turn needle is actuated by a gyro wheel operated either electrically or by a venturi tube or vacuum pump. Free air entering through a nozzle impinges on the paddles of the gyro wheel, causing it to rotate at approximately 9,000 rpm. The gyro wheel is mounted **vertically** and rotates about its **horizontal** (athwartships) axis.

The basic principle which governs the operation of the turn needle is "Gyroscopic Precession". The spinning gyro wheel, or rotor, is mounted in a gimbal ring. When the airplane turns to the right or left, the gyro wheel "precesses" about its turning axis, and "rolls" the gimbal ring. The rolling motion of the gimbal ring in turn rotates the turn needle on the face of the instrument. A spring returns the gyro to neutral when the airplane ceases to turn.

The Turn Indicator indicates the **rate** of the turn, not the **amount** of the turn. Thus a standard rate, or rate one, turn will give a rate of turn of 3° per second — or 360° in two minutes.

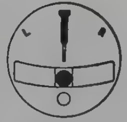


Fig. 49.
Straight and Level.

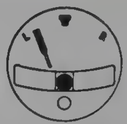


Fig. 50.
Left Turn. Correct Bank.

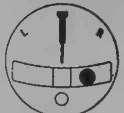


Fig. 51.
Straight.
Right Wing Low.

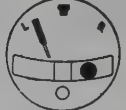


Fig. 52.
Left Turn.
Skid Outwards.

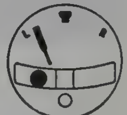


Fig. 53.
Left Turn.
Sideslip Inwards.

The instrument is usually calibrated to indicate a Rate One Turn when the turn needle is centred on one of the Indexes seen either side of the Centre Index (Fig. 48).

In a straight and level flight, the ball and needle are both centred. (Fig. 49.)

In a correctly banked turn, the needle indicates the rate of the turn. The forces acting on the ball **cause it to remain centred.** (Fig. 50.)

If one wing is permitted to drop, the ball will roll towards the side of the low wing. The needle in Fig. 51 shows the airplane to be flying straight, but the ball indicates it to be right wing low.

If the airplane is not sufficiently banked in a turn, a skid towards the outside of the turn will occur. In Fig. 52, the needle indicates a left turn, the ball a right skid outwards.

When the airplane is overbanked in a turn, it will sideslip inwards. The needle in Fig. 53 indicates a left turn, the ball a sideslip inwards.

Turn Co-Ordinator

Many modern airplane instrument panels use a Turn Co-

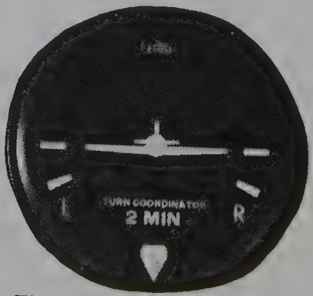


Fig. 54. Turn Co-Ordinator.

Ordinator to replace the more familiar turn and bank instrument. It works on the same principle as the Turn and Slip. A small airplane replaces the needle. It rotates to show that the airplane is turning. When the airplane is turning left or right, the miniature airplane banks in the direction of the turn. When the wing of the airplane is aligned with one of the marks, the airplane is in a standard rate, or rate one, turn.

The ball indicator gives the same indications as the ball indicator of the Turn and Slip Indicator.

THE GYROSYN COMPASS

The Gyrosyn Compass combines the functions of both the Directional Gyro and the Magnetic Compass.

It provides stable compass headings in rough air.

It is north-seeking like a Magnetic Compass, but is free from northerly turning error and oscillation.

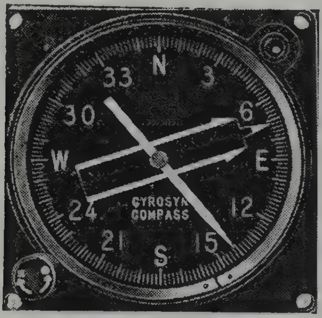


Fig. 55. Sperry Gyrosyn Compass.

It does not "drift" nor require resetting like the Directional Gyro does.

The system is light in weight and takes up little space in the airplane. The Gyrosyn Compass System consists of a Flux Valve, Directional Gyro unit, Amplifier and the Indicator on the instrument panel.

The **Flux Valve.** Unlike the magnetic compass, in which a north seeking magnet aligns itself with the earth's magnetic field, the Flux Valve **senses** the earth's magnetic lines of force through the principle known as electromagnetic induction. In the Flux Valve, the earth's magnetic lines of force, or flux, cause a voltage to be *induced* in the coils of a sensing unit. By aligning the coils with the longitudinal axis of the airplane, direction can be determined from the induced voltages, which change with each change in the heading of the airplane. This information is transmitted electronically to the Gyro.

Since it is the horizontal component of the earth's magnetic field which provides directional guidance, the Flux Valve sensing unit is penduously installed (to keep it horizontal) inside a case filled with damping fluid, which is usually mounted in a wing tip, remote from local magnetic disturbances in the airframe.

The **Directional Gyro Unit** is essentially the same as the Directional Gyro described elsewhere, except that it is slaved to the earth's magnetic lines of force by the signal received from the Flux Valve.

The **Amplifier** amplifies the phase of the signals from the Flux Valve.

Fundamentally, the Gyrosyn Compass is a Directional Gyro with a magnetic "sense" — a Directional Gyro Synchronized with the earth's magnetic meridian by means of the Flux Valve.

The dial of the Gyrosyn Compass System is shown in Fig. 55. The movable pointer points to the magnetic heading of the airplane. The Course Indicator (parallel lines) can be set to any desired heading for easy reference.

At the upper right of the dial is a small round window in which a dot and cross appear alternately, indicating that the gyro is synchronized with the earth's magnetic lines of force. If one or the other predominates, turn the knob towards either the dot or cross as required, until both appear with equal regularity. The gyro is then synchronized.

Operation:
(i) Switch on the electrical supply.
(ii) Push in and turn the knob at lower left to synchronize the gyro — that is, line it up with magnetic north initially.
(iii) Turn the knob (without pushing in) to set the Course Indicator to the desired heading.

Some Gyrosyns are fitted with a dial switch. In one position, the complete system is in operation. In the other position, the Flux Valve is shut off and the instrument operates as a free Directional Gyro. This feature is for use in high polar latitudes or under any other circumstances where magnetic indications are unreliable.

Aero Engines . . .

Present day aircraft engines are modern masterpieces of precision workmanship and quality material and represent the achievement of years of research and engineering experience in their design.

The fact is that the life and efficiency of an aero engine depends to an appreciable extent upon the use or abuse the motor suffers at the hands of the pilot. Sudden "gunning" of the throttle places undesirable stresses on the working parts of an engine. Switching off an overheated motor is a form of torture that should be punishable by a heavy fine. Operating an aero engine at continuously high power settings may progressively reduce the reliability of the enline and the safe period between overhauls.

Proper care and concern in the handling and running of an aero engine at the hands of an experienced pilot will keep that engine off the old age pension long beyond its normal span.

It is by no means necessary that a pilot should learn to be a mechanical engineer, but an elementary knowledge of the principles and construction of internal combustion engines is necessary if the proper procedure in running and handling is to be observed. (Note: An internal combustion engine is one in which the heat is created by the burning of the fuel within the engine itself, rather than in an external furnace, as in the case of steam engines.)

Very possibly some students who expect to fly as private pilots only will choose to skip over some of the details of engine design and construction that are described in this chapter. Those aspiring to be commercial pilots and who may some day fly as bush pilots in the more isolated areas of this country should have a more detailed knowledge of how an engine operates. Many a bush pilot has had to be his own mechanic. For this reason, a detailed description of an engine's operation is contained in the following pages.

POWER

A piston driven aero engine is frequently referred to as a "power plant" and its product is power. First then, let us consider briefly the basic meaning of these terms. Power may be simply defined as the rate of doing **Work.** Work, in turn, is **Heat** transformed into **Energy.** The amount of power an internal combustion engine can produce depends on the amount of **heat** which can be generated by the burning gases. This, in turn, is limited by the **mechanical ability** of the engine to transform as much of this heat as possible into useful work.

The standard unit in use for measuring the power produced by an engine is **One Horsepower.** This represents the amount of work done when 33,000 lbs. are raised 1 ft. in one minute.

The power developed within an internal combustion engine is called **Indicated Horse Power.** Due to friction, etc., all this power is not available for useful work. The power which is available, after friction and other losses, is called **Brake Horse Power (BHP).**

The total amount of Indicated Horse Power an engine can produce may be represented by the formula:

$$\frac{PLAN}{33{,}000} \quad \text{That is: } \frac{P \times L \times A \times N}{33{,}000}$$

Where P = The Mean Pressure in lb. per sq. inch.
L = The length of the stroke in feet.
A = The area of the piston in sq. inches.
N = The number of impulses (or power strokes) per minute.

"P", the PRESSURE, in an internal combustion engine is obtained by admitting a mixture of vaporized gasoline and air into a cylinder, compressing this mixture, and burning it. As the gases burn, they expand, exerting an enormous pressure on the piston head. The piston is driven down, pushing the connecting rod down, which in turn forces the crankshaft to turn at high speed. Note that the piston is driven down **not** by an "explosion" of gases, as is commonly supposed by beginners, but by their burning (or combustion) expansion and resultant **pressure.**

"L", the length of the STROKE, is the distance the piston travels up or down inside the cylinder.

"A", the AREA of the piston, means the area of the top or "head" of the piston.

"N", the number of IMPULSES, is the number of times the engine fires in one minute. In a 4-stroke engine this would be equivalent to **half** the number of revolutions of the crankshaft for each cylinder multiplied by the number of cylinders.

Aviation progress demands continued search for greater and greater power output from aircraft motors. This involves constant improvement in the mechanical ability of engines to produce power from heat.

Since the horse power (hp) of an engine is the total product of four factors referred to in the formula, it is obvious that an increase of all, or any one or more of these, will increase the power output of the engine.

"L" and "A", being dependent on the length of the stroke and area of the piston, are fixed and cannot be varied without altering the design of the engine.

"P" and "N", however, are variable, and are the factors which can be stepped up in the search for greater power.

Some of the means adopted to boost Mean Effective Pressure are: High compression ratios; Higher octane fuels; Supercharging; Improved scavenging; etc.

An engine's power varies in direct proportion to the speed at which it is run. Hence, the pilot may at will vary "N" by manipulation of the throttle. Designers seek to improve this factor by the design of high speed engines.

POWER DEFINITIONS

M.E.P. — Mean Effective Pressure, is the average pressure within the cylinder during the entire period of the power stroke, from the time the piston is at Top Dead Centre until it reaches Bottom Dead Centre.

METO POWER is Maximum Except Take-off Power.

B.M.E.P. — Brake Mean Effective Pressure is the M.E.P. available to produce the net power delivered at the propeller shaft (BHP).

TYPES OF COMBUSTION ENGINES

The three main types of piston engines in current use are **Radial, In-Line** and **Horizontally Opposed.** They derive their names from the arrangement of their cylinders around the central crankshaft.

The horizontally opposed type is most commonly used in general aviation airplanes.

HORIZONTALLY OPPOSED

The horizontally opposed engine, as the name implies, has two banks of cylinders working on the same crankshaft which lie directly opposite to each other in the horizontal plane. There may be four, six or eight cylinders.

The outstanding advantage of this motor type is its flat, or "pancake" shape. Its small frontal area generates less drag.

RADIAL

The cylinders are arranged radially around a "barrel-

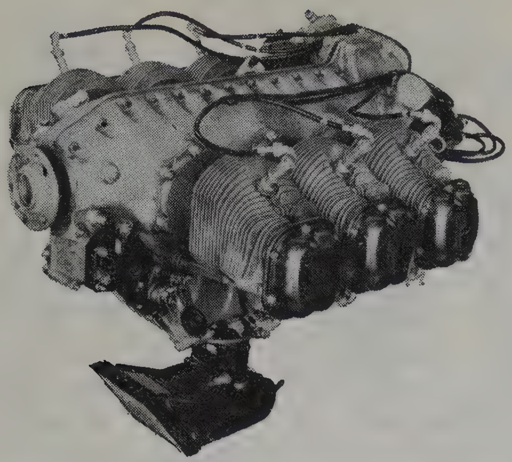


Fig. 1. Continental Horizontally Opposed Engine.

shaped'' crankcase. This type of engine always has an odd number of cylinders (five, seven, nine, etc.). This is necessary because the firing order is *alternate* — e.g. 1-3-5-2-4. The usual limitation is nine cylinders in a row. Larger engines of this type have two, three, or more rows working on a two or three throw crankshaft.

Radial engines are ''dry sump'', or pressure lubricated.

The radial engine has an acceptable ratio of weight to horsepower developed and is easy to maintain. However, these advantages are outweighed by its poor shape that considerably increases parasite drag and reduces forward visibility from the cabin.

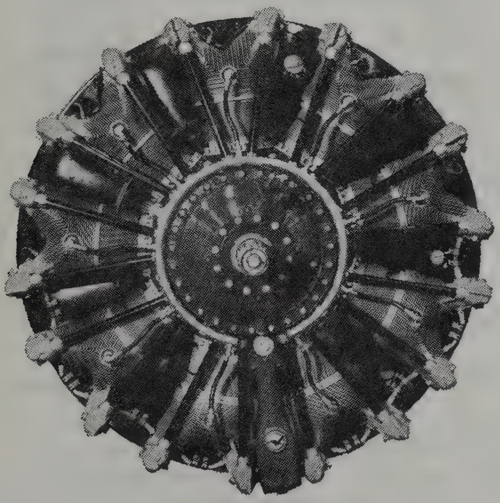


Fig. 2. P & W Wasp Junior Radial Engine.

IN-LINE

In this type of engine, the cylinders are arranged side by side in a row along the crankcase. Each separate piston works on an individual crank-throw.

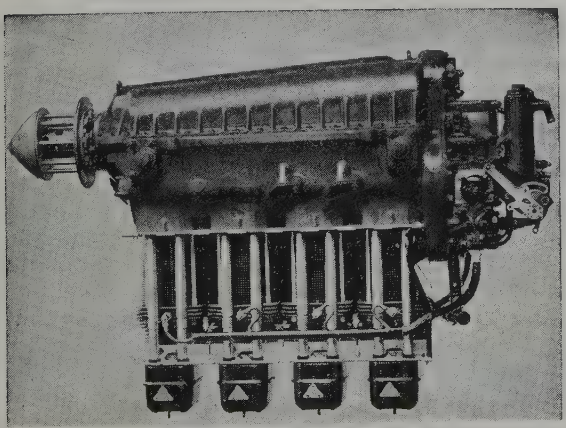


Fig. 3. Gipsy In-Line Engine.

The practical limit is six cylinders in one row, the reason being that a crankshaft long enough to accommodate a greater number of cylinders would be difficult to make stiff enough to avoid vibration. Where a larger number of cylinders is required, it is customary to arrange these in two or more banks. Hence, there are V-Type, X-Type and H-Type in-line engines which have two crankshafts side by side.

Some in-line engines are inverted, that is, the engine is installed upside down to provide better visibility for the pilot. These obviously must be of the ''dry sump'' or pressure lubricated type.

The in-line engine, with its small front area, generates little parasite drag.

The in-line engine is found today mostly in vintage airplanes.

CONSTRUCTION OF A RECIPROCATING ENGINE

The basic parts of a reciprocating engine are the crankcase, cylinders, pistons, connecting rods, valves, valve operating mechanism, camshaft and crankshaft. In the head of each cylinder are located the valves and spark plugs. One of the valves is in a passage leading to the induction system; the other in a passage leading to the exhaust system. Inside each cylinder is a movable piston connected to a crankshaft by a connecting rod.

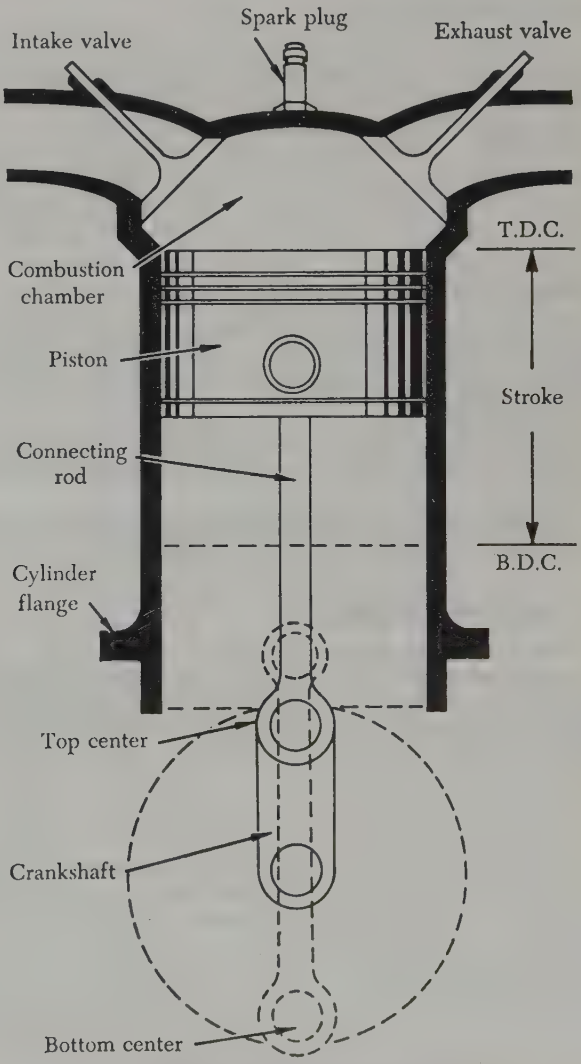


Fig. 4. Basic Parts of a Reciprocating Engine.

The cylinder and the cylinder head are "finned" to dissipate heat. The crankshaft converts the reciprocating motion of the piston into rotation and transmits power from the piston to drive the propeller.

The bore of a cylinder is its inside diameter. The stroke is the distance the piston moves from one end of the cylinder to the other, that is, from T.D.C. (top dead centre) to B.D.C. (bottom dead centre). See Fig. 4.

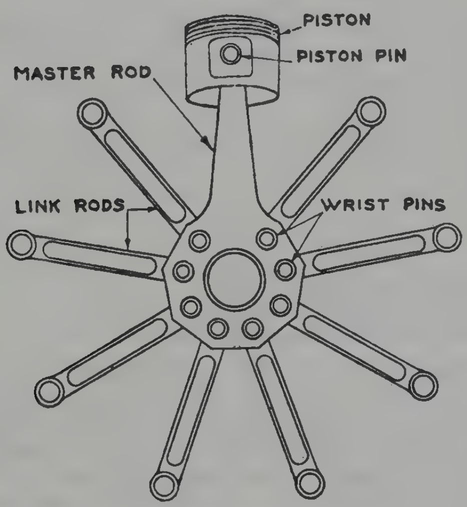


Fig. 5. Radial Connecting Rod.

REDUCTION GEARS

Many modern engines are geared. This means that the engine turns at a higher speed than the propeller which it drives. In this way, geared engines are made to develop greater power than direct drive engines with the same propeller speed.

The gearing consists of two sets of gear wheels. One of these is driven by the crankshaft and meshes with the other which, in turn, drives the propeller hub shaft. The reduction in speed is governed by the relative number of teeth in the two sets of gears.

AUXILIARY DRIVES

The crankshaft drives the propeller. It is also made to drive various **Auxiliary Gears** which in turn drive oil pumps, magnetos, generators, dynamos, air compressors, and other essential auxiliaries.

The auxiliary gears are generally grouped in a **Gear Box** placed at the rear of the engine, to avoid increasing the frontal area.

In some cases a single flexible **Half-Time Shaft**, driven by the crankshaft, is used to drive all the auxiliary gears.

THE 4-STROKE CYCLE

Almost all piston engines in use operate on what is known as the **Four-Stroke Cycle.** This means that the piston travels four strokes (two up and two down) to complete one cycle. During this operation the crankshaft revolves through 2 complete revolutions.

1. The Induction Stroke

The inlet valve open, the piston moves down from the top to the bottom of the cylinder creating a negative pressure. By this action, air, which surrounds the conventional suction carburetor and which is approximately at atmospheric pressure, is drawn through the carburetor where it picks up a suitable amount of fuel (about one part gasoline to fifteen parts air) and the resulting fuel/air mixture rushes in past the open intake valve into the cylinder to fill the space above the piston. The amount of mixture which enters the cylinder will depend on the throttle opening. The exhaust valve remains closed.

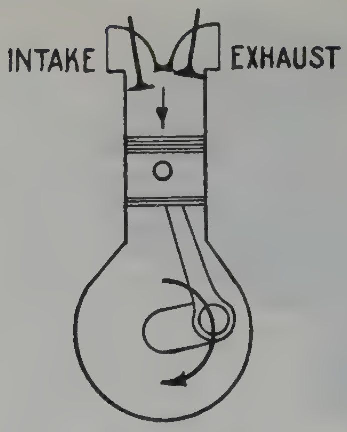


Fig. 6. Induction.

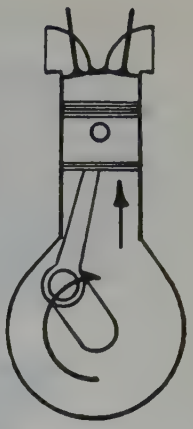


Fig. 7. Compression.

2. The Compression Stroke

Both valves closed, the piston moves up from the bottom to the top of the cylinder, compressing the mixture.

The volume in the cylinder above the piston when it is at the bottom of the compression stroke compared to the volume when it has moved up to the top of the stroke is known as the **Compression Ratio.** e.g. 3:1.

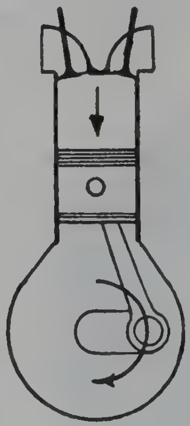


Fig. 8. Power.

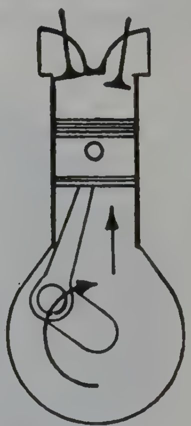


Fig. 9. Exhaust.

3. The Power Stroke

Both valves closed. The compressed mixture is fired by a spark plug. The burning gases, expanding under tremendous heat, create the pressure which drives the piston down with terrific force. This force is sufficient to complete the other three strokes in addition to providing the energy required for useful work.

4. The Exhaust Stroke

Exhaust valve open. The piston moves up from the bottom to the top of the cylinder, pushing the burnt gases out past the open exhaust valve. The inlet valve remains closed.

TIMING

In discussing the Four Stroke Cycle, we considered the various strokes as beginning and ending as the piston reached the top or the bottom of the cylinder. In actual practice, better performance is obtained from the engine by what is known as Valve Lead, Lag, and Overlap. Valves require time to open and close. They therefore are timed to open early and close late in order not to waste any of the induction or exhaust strokes.

Valve LEAD is timing the valve to open **early.**

Valve LAG is timing the valve to close **late.**

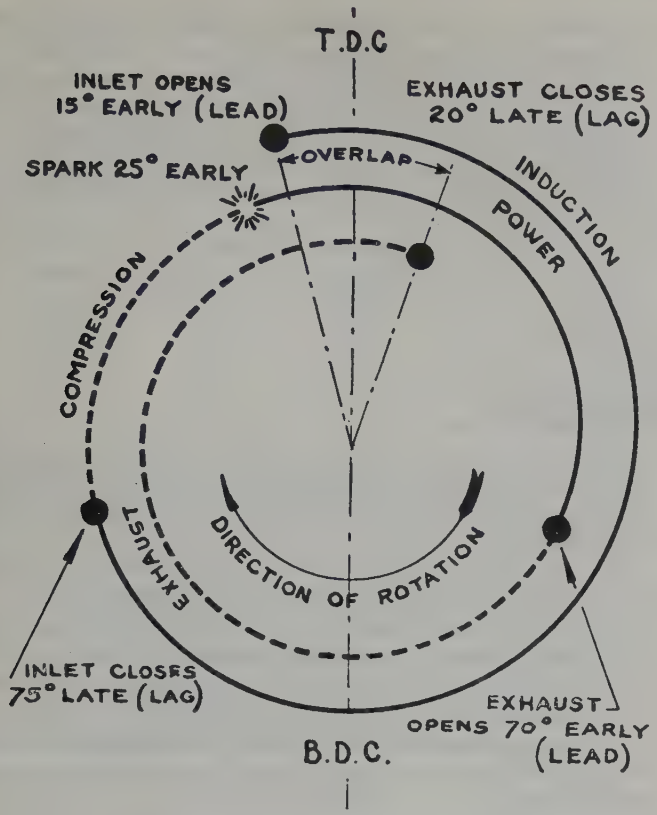

T.D.C
INLET OPENS 15° EARLY (LEAD)
EXHAUST CLOSES 20° LATE (LAG)
SPARK 25° EARLY
OVERLAP
INDUCTION
POWER
COMPRESSION
EXHAUST
DIRECTION OF ROTATION
INLET CLOSES 75° LATE (LAG)
EXHAUST OPENS 70° EARLY (LEAD)
B.D.C.

Fig. 10. Engine Timing Diagram.

Valve OVERLAP is allowing both valves to remain open at the same time.

Fig. 10 shows a typical timing diagram for a modern high speed engine. T.D.C. refers to Top Dead Centre, the point where the piston reaches the top of the cylinder, and B.D.C. to Bottom Dead Centre. The circles represent the rotation of the crankshaft, 180° between T.D.C. and B.D.C.

Note:

1. That the Inlet Valve opens 15° early on the Induction Stroke.

2. The Inlet closes 75° late on the Induction Stroke in order to use the momentum of the incoming gases to force the maximum charge into the cylinder.

3. The Spark occurs 25° early on the Power Stroke in order to allow complete combustion of the mixture so that the maximum pressure is reached when the piston passes T.D.C. and is travelling down on the Power Stroke.

4. The Exhaust opens 70° early on the Exhaust Stroke because any pressure remaining in the cylinder after B.D.C. is passed opposes the motion of the piston coming up on the Exhaust Stroke.

5. The Exhaust closes 20° late on the Exhaust Stroke. This means that both valves are open together, or **overlapped** on the Induction and Exhaust Strokes for 35°. The Exhaust Valve remaining open late, helps to "scavenge" the burnt gases. The momentum of the outgoing exhaust gases leaves a partial vacuum in the cylinder which accelerates the entry of the incoming charge.

Valve Clearances

A clearance is necessary between the valve stem and the rocker to prevent the valve being forced off its seat when it gets hot and expands. This is called the **Valve Clearance**, or sometimes **Tappet Clearance**, of the engine.

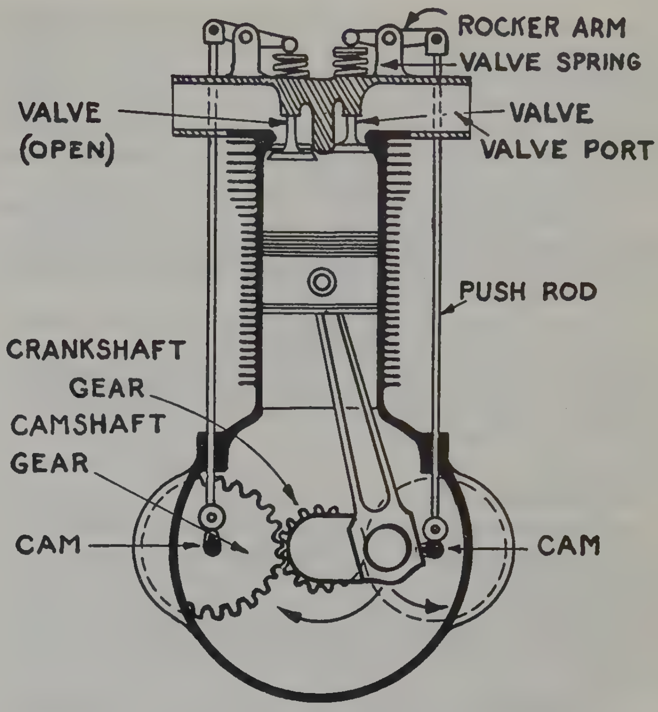


Fig. 11. Valve Mechanism.

The clearances are set cold, allowance being made for the correct clearance to be attained when the valves reach their normal working temperature.

Clearances set too wide will cause a loss of power, vibration and excessive wear.

Clearances set too close are apt to warp the valves and cause serious trouble.

COOLING

We have previously considered the fact that the source of all power is heat. It will therefore be obvious that the modern aero engine, which is a unit designed to develop great power, must generate terrific heat. The heat of combustion reaches temperatures inside the cylinder actually as high as 2500°C. An appreciable portion of this heat is absorbed by the engine parts, the cylinder walls, piston heads, etc. This would cause excessive overheating — to the extent of actually fusing or melting the metal parts — if some means were not provided for dissipating it.

The engines of some older airplanes use a liquid coolant, but, by far, the most common method of dissipating engine heat is by circulating cooling air around the engine cylinders. Both horizontally opposed and radial engines are air cooled. Some in line engines are air cooled; a few models were liquid cooled.

AIR COOLING

In air cooled engines, **Fins** are added to the cylinders to provide a greater area of metal to absorb the heat. It is ram air passing over the fins that absorbs this excess heat and carries it away. This cooling air enters the engine compartment through openings in the front of the engine cowl and is expelled through openings at the rear of the cowling.

Baffles are used to force the cooling air around the cylinders.

On low performance airplanes, the openings to expel the cooling air are of fixed size. In high performance airplanes, the size of these openings is usually controlled by **cowl flaps**. During high power settings, such as during take-off and climb, the forward speed of the airplane is low and engine power is high. More cooling air is necessary to dissipate the higher heat generated by the harder working engine. During cruise, less cooling air is required. Since the cooling air flowing over the cylinders causes drag, in a high performance airplane it is of benefit to reduce the amount of air entering the engine compartment when it is not needed. This is effected by the addition of cowl flaps that are controlled from the cabin. They are used fully open for taxi, take-off and climb and are closed or partially closed for cruise and descent.

Cooling fans are sometimes mounted on the front of the engine and are gear-driven from the engine crankshaft. They assist the flow of cooling air at high altitudes where the weight-flow of cooling air is becoming light.

On some airplanes, the exhaust gases are directed through **Augmentor Tubes,** or Jet Pumps, which produce a suction strong enough to increase the flow of cooling air past the cylinders. The augmentor tubes also produce additional thrust sufficient to offset the drag of the cooling air.

LUBRICATION

Lubricating oil has four important functions to perform:

1. **Cooling** — Carries away excessive heat generated by the engine.
2. **Sealing** — Provides seal between piston rings and cylinder walls, preventing "blow-by" loss of power and excessive oil consumption.
3. **Lubrication** — Maintains oil film between moving parts, preventing wear through metal to metal contact.
4. **Flushing** — Cleans and flushes interior of engine of contaminants which enter or are formed during combustion.

REQUIREMENTS OF GOOD OIL

1. **Viscosity** — *i.e. Resistance to flow.* "Stickiness" or "body."

Good viscosity gives proper distribution of oil throughout the engine and prevents rupturing of the oil film which lubricates the engine parts over the wide range of temperatures in which aero engines work. An oil with a high **Viscosity Index** is one in which the changes in viscosity, due to widely varying operating temperatures, are small.

The use of oil of too high viscosity for existing climatic temperatures will cause **high oil pressure.**

The use of oil of too low viscosity for existing climatic temperatures will cause **low oil pressure.**

2. **High Flash Point** — i.e. *The temperature beyond which a fluid will ignite.* This should be in excess of the highest engine temperature.

3. **Low Carbon Content** — To leave as little carbon as possible should oil work past the scraper ring and burn. Good oil should also have a low wax content. Oils which have good resistant to deterioration and the formation of lacquer and carbon deposits are said to have good **Oxidation Stability.**

4. **Low Pour Point** — i.e. *The temperature at which a fluid solidifies.* Necessary for cold weather starting.

ADDITIVES

Some oils contain additives. These may be classified as follows:

1. **Detergents** — Those which improve engine cleanliness.
2. **Oxidation Inhibitors** — Those which improve oil stability.
3. **Anticorrosion Additives** — Those which deter corrosion.
4. **Pour Point Depressants** — Those which lower the pour point.

There are also various other "improvers" which increase film-strength and viscosity and which decrease foaming characteristics.

It is important that oil which contains additives should be added ONLY to oil of the same type.

GRADE OF OIL

The grade of oil recommended for various seasonal aero engine requirements is designated by an **S.A.E. Number,** or by the **Saybolt Universal Viscosity,** which is expressed in "seconds". The engine oil grade is, therefore, frequently referred to as, say, S.A.E. 50, or as a "100 second oil". In the United States it is common practice to add 1000 to the Saybolt Viscosity, so that this particular grade could also be referred to as "Grade 1100". For engines of moderate horse-power, the following grades are generally used:

	Saybolt Viscosity	S.A.E. Number	U.S. Grade
Summer	120	60	1120
Fall or Spring	100	50	1100
Winter	80	40	1080
Arctic	65	30	1065

OIL TEMPERATURE

It is necessary to keep the oil temperature in an operating engine between certain well defined limits because the lubrication of the engine depends on the viscosity of the oil which, in turn, is governed by oil temperature.

If the oil gets too hot, its viscosity will be impaired and may not be enough to keep a good film of oil on the engine parts.

If it gets too cold, the oil will become thick and will not flow through the passageways, resulting in improper lubrication.

Oil temperature is monitored by means of an oil temperature gauge which is installed on the instrument panel of the airplane.

Engine manufacturers always specify operating limits which must be strictly observed, otherwise the life of the engine may be seriously impaired.

METHODS OF LUBRICATION.

1. **Force Feed:** In this method the oil is forced under pressure from a pressure pump through the hollow crankshaft and lubricates the main and big end bearings under pressure. It is then sprayed through tiny holes to lubricate the remaining parts of the engine by a fine mist, or spray.

2. **Splash:** The oil is contained in a sump, or reservoir, at the bottom of the engine. It is churned by the revolving crankshaft into a heavy mist which splashes over the various engine parts. This type of lubrication is practically obsolete in present day airplane engines but will be found in the engines of some of the older airplanes that are still flying today.

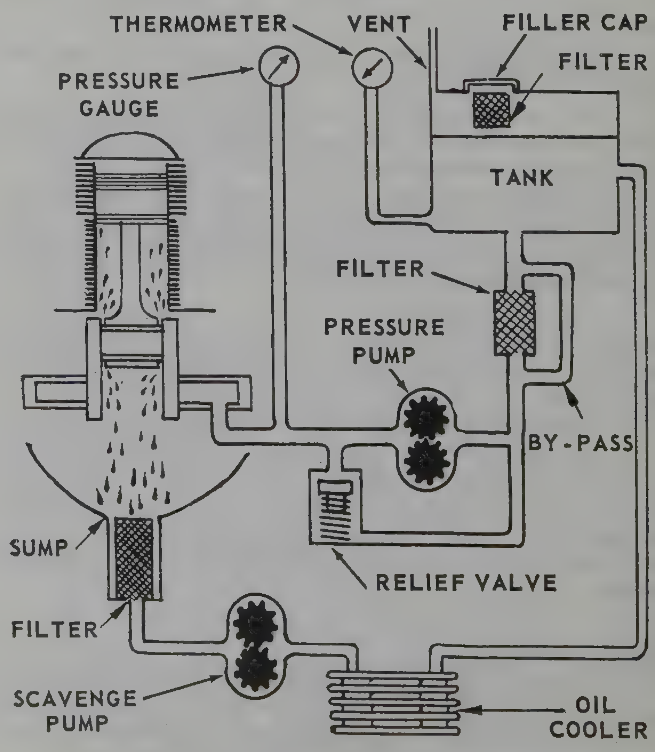


Fig. 12. Dry Sump Lubrication System.

Force Feed: Dry Sump Lubrication

A **Dry Sump** engine is one in which the oil is contained in a separate tank and is forced under pressure from a **Pressure Pump** through the hollow crankshaft to lubricate the engine by the Force Feed method. The oil is then drained into a **Sump** from which it is pumped by a **Scavenging Pump**, which has 20% greater capacity than the pressure pump — to ensure that the oil does not accumulate in the engine. Thence it passes through an **Oil Cooler** and is returned to the tank.

Fig. 12 shows the system of oil circulation in a Dry Sump engine. The **By-pass** around the **Filter** is provided to prevent damage in case of failure (through neglect or carelessness) to clean the filter. In this event, dirty oil is considered definitely a lesser evil than no oil at all! The by-pass is also a safety device allowing the oil to return to the tank without damaging parts such as the filter in case the pressure should become excessive. The **Pressure Relief Valve** provides a means of regulating the oil pressure.

Oil pressure is monitored by means of an oil pressure gauge on the instrument panel of the airplane.

THE FUEL SYSTEM

The aircraft fuel system stores and delivers the proper amount of fuel at the right pressure to meet the demands of the engine. It must deliver this fuel reliably throughout all phases of flight, including violent maneuvers and sudden acceleration and deceleration.

There are usually several tanks, even in a simple system, to store the quantity of fuel required to give the airplane reasonable range. These tanks are usually located in the wings, although extra tanks may be located in the cabin area. A line leads from each tank to a selector valve in the cockpit, by which the pilot is able to select the tank from which fuel is to be delivered.

TYPES OF FUEL SYSTEM

GRAVITY FEED FUEL SYSTEM

This is the simplest type of fuel system and is still in use on many high wing, low-powered airplanes. The fuel tanks are mounted in the wings above the carburetor, with gravity causing the fuel to flow from the tanks, past the fuel selector valve to the carburetor. A strainer filters the fuel before it reaches the carburetor. A drain allows removal of water and sediment trapped at the strainer. A primer sprays raw fuel into the intake manifold system or directly into the cylinder to aid engine starting, particularly in cold weather.

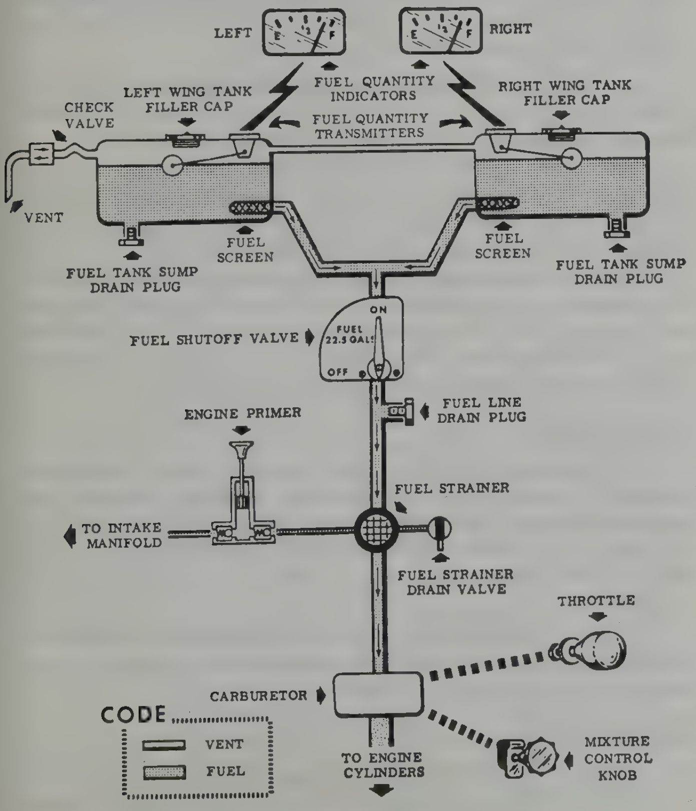


Fig. 13. Gravity Feed Fuel System.

FUEL PUMP FUEL SYSTEM

This type of fuel system differs from the gravity feed type in that an engine driven fuel pump supplies the pressure that keeps the fuel flowing to the engine. This type of system is in use in all low wing airplanes and in any airplane with a high performance engine. Such a system incorporates as well as the basic pump, auxiliary electric pumps or booster pumps that serve in emergency in case the engine driven pump fails. The booster pump, operated by a switch on the instrument panel, is also used to start the fuel flowing under pressure before the engine is running.

A fuel pressure gauge, mounted on the cockpit panel, gives a visual indication that the fuel system is working by giving a reading of the pressure of fuel entering the carburetor.

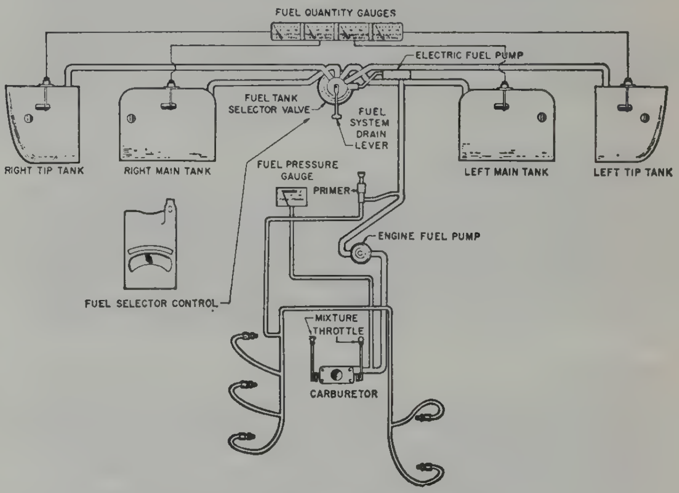


Fig. 14. Fuel Pump Fuel System.

FUEL TANKS

The location, size and shape of fuel tanks vary with the type of airplane in which they are installed. They are most often located in the wings. Wing tip tanks are common.

The tanks are made of materials that will not react chemically with any aviation fuel. Aluminum alloy is most widely used. Synthetic rubber or nylon bladder type fuel cells are also in use. This latter type depends upon the structure of the cavity in which it sits to support the weight of fuel it holds.

Usually a drain is provided at the lowest point of the tank through which water and sediment, which are heavier than fuel and therefore settle to the lowest point of the fuel tank, can be drained.

Overflow drains are also incorporated to release fuel and prevent tanks from bursting when fuel expands in the tanks. Such expansion takes place when an airplane is parked in direct sunlight and the fuel becomes heated.

The top of each tank is vented to the outside air to maintain atmospheric pressure within the tank. Tanks are also fitted with internal baffles to resist fuel surging caused by changes in attitude of the airplane. The tanks are filled through a filler neck on the upper surface of the wing. Caps for the filler neck have locking devices to prevent accidental loss during flight.

Information about the capacity of each tank is usually posted near the fuel selector valve in the cockpit of the airplane.

FUEL SELECTOR VALVE

A fuel selector valve in the cockpit permits the pilot to select the tank from which he wishes to draw fuel. It also has an "Off" position which closes off the fuel flow entirely. When the airplane is parked, the "Off" position may be selected.

FUEL LINES AND FILTERS

The various tanks and other components of the fuel system are joined together by fuel lines made of aluminum alloy metal tubing and flexible synthetic rubber or teflon hose.

Coarse mesh strainers are installed in the tank outlets and often in the tank filler necks. Other strainers, made of fine mesh, are installed in the carburetor fuel inlets and in the fuel lines.

The main strainer is located at the lowest point in the fuel system. Its purpose is to prevent any foreign matter from entering the carburetor and to trap any small amounts of water that may be present in the system.

It is good practice to drain the strainers prior to every flight to remove from the system any water that may be in the fuel. In cold weather, this water might freeze and stop the fuel flow. In warm weather, excessive water entering the carburetor could stop the engine.

FUEL QUANTITY GAUGE

Fuel quantity gauges are mounted on the instrument panel and give a visual indication of the amount of fuel in each tank. A pilot should never assume that the instrument is correct but should make a visual check of each fuel tank before initiating a flight.

FUEL PRIMER

A small hand pump is located on the instrument panel. This is a primer that is used to pump fuel into the engine prior to starting. Ordinarily, it is needed only in cold weather. A pilot should be careful not to overprime since this action may flood the engine and make it hard to start and, in some cases, may even cause a fire.

FUELS

Fuels for modern high compression engines must burn slowly and expand evenly rather than "explode" quickly. The fuels which possess this quality are known as High Octane fuels.

The **Octane Rating** of a fuel is arrived at as follows:

Octane is a substance which possesses **minimum** detonating qualities.

Heptane is a substance which possesses **maximum** detonating qualities.

The proportion of Octane to Heptane in a fuel is expressed as percentage. Hence, 73 Octane means 73% Octane and 27% Heptane characteristics in the fuel.

The natural gas limit is 72 Octane. Fuels of higher Octane than this are treated with Tetra Ethyl Lead, or are "cracked" by a heat process which increases their volatility. They are also treated with sulphuric acid, lye, etc., to remove the gum, acid and other impurities.

Octane numbers go only as high as 100. Beyond this number, the anti knock value of the fuel is expressed as a **Performance Number.**

Fuel grades are usually indicated by two numbers, e.g.: Grade 80/87. The first number (80) indicates the octane rating at **lean mixture** conditions, and the second (87) at **rich mixture.** Grade 100/130 indicates a fuel with a lean mixture Performance Number (or Octane Rating) of 100, and a rich mixture Performance Number of 130.

The following are the approximate ratings for the most common fuels and their colour.

Low power output	Grade 80/87	Red
Medium power output	Grade 100/130 (low lead)	Blue
Medium power output	Grade 100/130 (high lead)	Green
High power output	Grade 115/145	Purple

It is the responsibility of the pilot to see that the proper fuel grade is used in refuelling his airplane. The Airplane Flight Manual always specifies what kind of fuel should be used and usually this information is also marked on a placard in the cockpit and also next to the filler cap.

If the proper grade of fuel is not available, use the next higher grade. Never use a lower grade. The engine will overheat badly and engine damage may occur.

The higher octane fuels, however, have more lead content and may cause trouble such as spark plug fouling. For that reason, when using a fuel with a higher octane rating than is recommended for your engine, keep the fuel flow on the rich side of normal lean to counteract the effect of increased combustion chamber deposits.

Never use automotive gasoline in airplanes. Its composition is such that it can cause vapour lock, pre-ignition and detonation. It is less stable than aviation gasoline and can form gum deposits.

PROBLEMS OF THE FUEL SYSTEM

DETONATION

Detonation is characterized by the inability of a fuel to burn slowly and is generally defined as an abnormally rapid combustion, replacing or occurring simultaneously with normal combustion. Detonation is also characterized by its almost instantaneous nature, as contrasted with the smooth progressive burning of normal combustion. Under conditions of detonation, cylinder pressures rise quickly and violently to peaks that are often beyond the structural limits of the combustion chamber. Detonation is dangerous and costly. It puts a high stress on engine parts and causes overheating, warped valves and piston damage. It is not always easy to detect. Cylinder head temperatures offer about the best appraisal of the unseen combustion process. A rapid increase in cylinder head temperature, unless explained by some other factor, often indicates detonation. Throttle reduction is the most immediate and surest remedy.

Cause: 1. Use of incorrect fuel. 2. Overheating, sometimes caused by pilot climbing too steeply, thereby reducing flow of air around the cylinders. 3. Too lean a mixture.

Temporary Remedy: In an emergency, use the mixture control full rich. This enriches the mixture, which in turn tends to cool the engine due to the evaporation of the raw gas in the cylinders. Also reduce the power as much as possible.

Permanent Remedy: Persistent detonation indicates that a fuel of too low octane is being used. *Use* **only** *fuel of the octane rating specified by the engine manufacturer.* If the handbook isn't available and there is any doubt in your mind, always guess an octane rating on the high side, never one too low.

PRE-IGNITION

Pre-ignition is another trouble-maker which is sometimes confused with detonation. Pre-ignition, however, is a premature ignition of the mixture due to glowing carbon particles, or "local hot spots". It is often experienced when attempting to start a hot engine and usually results in a backfire through the intake manifold.

Damage to an engine from pre-ignition can be disastrous, causing warped pistons, cracked cylinder heads and other serious damage.

VAPOUR LOCK

Vapour lock in the fuel line can be caused by high atmospheric temperatures, causing the gas to vaporize and block the flow of liquid fuel in the line.

THE CARBURETOR

The heat energy in an internal combustion engine is developed from the burning of a mixture of gasoline and air.

The function of the carburetor is to measure the correct quantity of gasoline, vaporize this fuel, mix it with air in the proper proportion and deliver the mixture to the cylinders.

In the fuel/air mixture delivered to the cylinders from the carburetor, the proportion of gasoline to air is governed by weight and not by volume.

The following fuel/air ratios (by weight) indicate the effect, on a typical engine, of varying the mixture ratio at full throttle, constant speed.

Richest Running Mixture	About 1 to 8
Best Power Mixture	" 1 to 14
Chemically Correct Mixture	" 1 to 15
Lowest Fuel Consumption Mixture	" 1 to 18
Leanest Running Mixture	" 1 to 20

Too Lean a mixture may cause rough engine operation, sudden "cutting out", "popping back" or back-firing, detonation, overheating, or appreciable loss of power.

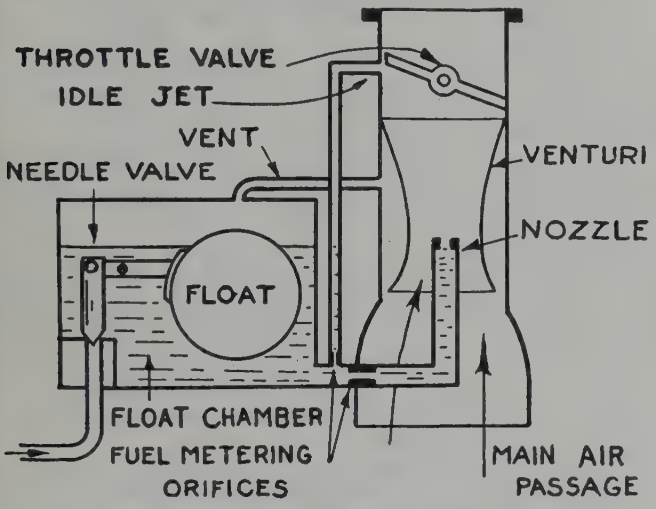


Fig. 15. Principle of a Simple Carburetor.

Too Rich a mixture may also cause rough engine operation, appreciable loss of power, or actual failure.

An engine will run hotter with a lean mixture than a rich mixture because the lean mixture is slower burning and the cylinder walls are exposed to high temperatures for a longer period of time. A richer mixture, on the other hand, burns more quickly, exposing the cylinder walls to high temperatures for a shorter period. Also, the additional fuel in the fuel/air mix of a richer mixture helps to cool the engine.

The complete carburetor is a highly complicated unit incorporating many devices necessary to control the mixture ratio under widely varying conditions imposed on the modern airplane engine. As such, it is beyond the scope of this manual. However, an explanation of the basic working principles of a simple carburetor and some of its additional parts will be of interest to the student pilot.

HOW THE CARBURETOR WORKS

Fuel flows through the fuel supply lines, past the fuel strainer and enters the carburetor at the **float (or needle) valve.** It flows into the **float chamber** where its level is controlled by a float which opens or closes the float valve as it rises or falls. When the float rises to a predetermined level, it shuts off the float valve. No additional fuel can then enter the carburetor until fuel is used by the engine.

The float chamber is vented so that the pressure in the chamber equalizes with the atmospheric pressure as the airplane climbs and descends.

The level of the gasoline in the float chamber governs the level of gasoline in the **nozzle,** as can be seen in Fig. 15. One of the problems of the carburetor is that sometimes the float may become punctured so that gasoline leaks into it increasing its weight. As a result, the level of gasoline in the chamber rises and gas overflows from the nozzle, thereby flooding the carburetor.

Outside air passes through the carburetor air filter which is located at the carburetor air intake in the front of the engine cowling. It is then drawn through the **venturi** (Fig. 15) where its speed is increased. A low pressure area is thereby created in the throat of the venturi. The reduced pressure around the nozzle draws the fuel, which is under atmospheric pressure, from the jet in the form of a fine spray.

The mixture of air and vaporized fuel, regulated in volume by the **throttle valve,** enters the intake manifold and thence is distributed to the individual cylinders.

The throttle valve is connected directly to the throttle control on the instrument panel of the airplane. By means of the throttle, the pilot is able to control the amount of fuel/air mix that enters the engine thereby controlling the power output. Forward movement of the throttle opens the throttle valve, increasing the volume of fuel/air mixture and consequently the speed of the engine. Aft movement of the throttle closes the throttle valve and reduces the volume of fuel/air mixture entering the engine.

Some portion of the gasoline in the fuel/air mixture does not vaporize and is still in liquid form when it enters the engine. It is vaporized by the heat of the engine. (This is one of several reasons why an engine should be warmed up slowly.)

IDLING

When an engine is idling, the throttle valve is closed and there is insufficient movement of air through the venturi to lower the pressure enough to draw fuel from the main nozzle. An **idle jet** is provided at the edge of the closed throttle valve where, owing to the narrow passage, the air accelerates and reduces the pressure enough to draw fuel from the idle jet.

ACCELERATION PUMP

During rapid acceleration, the fuel in liquid form, which travels to the cylinders along with the vaporized fuel and air, is unable to increase its velocity as rapidly as does the air. This causes a temporary **leanness** at the cylinders which must be compensated for by temporarily adding more fuel at the carburetor. This is accomplished by the **Acceleration Pump.** The device consists of a piston controlled by the throttle which works up and down in a cylinder containing gasoline at the float level. The piston is drilled with two holes beneath which is a **Check Valve.** When the throttle is opened slowly, the check valve remains open and no fuel is pumped. When the throttle is opened quickly, however, the check valve closes and the fuel in the cylinder is pumped into the air stream through the **Economizer Discharge Needle.**

MIXTURE CONTROL

The need to have a mixture control system is occasioned by the fact that, as altitude increases, the density of the air decreases. Carburetors are normally calibrated for sea level operation, which means that the correct mixture of fuel and air will be obtained at sea level with the mixture control in the full rich position. As altitude increases, a given **volume** of air **weighs** less. It is obvious then that at higher altitudes, the proportion of air by **weight** to that of fuel will become less although the volume remains the same. (Regardless of altitude, the amount of fuel entering the carburetor remains approximately the same for any given throttle setting if the position of the mixture control is not changed.) The mixture, therefore, becomes over-rich, causing waste of fuel and loss of power.

To correct this condition, a mixture control is fitted to the carburetor. This device adjusts the amount of gas being drawn from the nozzle and thereby restores the proper fuel to air mix.

The mixture control, on some airplanes, is an automatic device. Most commonly, it is a manually operated control that is operated by the pilot.

THE MANUAL MIXTURE CONTROL

In a manually operated system, the amount of fuel that is drawn from the nozzle to mix with the air is governed by the mixture control that is located on the instrument panel. By adjusting this control, the fuel to air ratio can be adjusted either to enrich the mixture or to lean it.

There are many different forms of mixture control device. The most common incorporates a **Needle Valve** which restricts the amount of fuel flowing from the float chamber to the nozzle. When the mixture control knob is moved fully forward, the needle valve retracts and allows fuel to flow freely to the nozzle. When the mixture control knob is moved aft, the needle moves into the fuel line to restrict the flow of fuel.

Another type of control is the **Back Suction System,** which is depicted in Fig. 16.

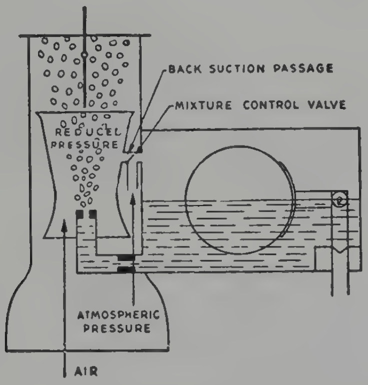


Fig. 16. Principle of the Back Suction Mixture Control.

A back suction pipe or passage interconnects the air space in the float chamber to the reduced pressure area in the venturi. Closing the Mixture Control Valve restricts the atmospheric pressure entering the float chamber, and the Back Suction Passage reduces the pressure in the chamber. This reduced pressure forces less fuel through the nozzle, and **leans the mixture.**

Idle Cut-off

Some engines are fitted with an Idle Cut-Off control to stop the engine. This is simply an extreme "lean" position of the mixture control, which reduces the pressure within the float chamber to such a low value that no fuel at all flows through the jet. Idle Cut-off will stop the engine immediately with no tendency towards pre-ignition or after-firing. It also makes the engine easy to start since the carburetor and fuel lines remain filled with gasoline.

Use of Manual Mixture Controls

Although specific instructions concerning mixture ratios are given for each type of airplane engine, a general rule to follow in using a manual mixture control is that the rich mixtures should be used at high power settings and the leaner mixtures at normal cruise power settings. Failure to observe the instructions pertaining to the use of the mixture control may easily result in engine overheating and detonation either of which will affect the reliability and useful life of the engine. In case of doubt, a mixture a little on the rich side is advisable as too lean a mixture can cause engine damage. The mixture control has the greatest effect, and all other engine controls a lesser effect, on engine operating temperatures.

A common method of adjusting a manually operated mixture control (for an engine with a fixed pitch propeller) is to observe the tachometer reading closely while moving the control from full rich towards lean. It will be observed that an increase in rpm occurs. The point at which this maximum rpm is first reached is called "rich best power". Further leaning will hold the rpm at maximum value for an appreciable movement of the control, whereupon still further leaning will cause a loss in rpm. The point where rpm begins to drop again from the maximum rpm value is called "lean best power".

For a given throttle opening and a given position of the mixture control, the mixture will become enriched as high altitude is attained. With loss in altitude, conversely, the mixture becomes leaner with unchanged mixture and throttle controls. Therefore, the mixture control should be readjusted for each 1,000 feet of change in altitude.

For take-off, climb, or landing, at or near sea level, the mixture control should be in the full-rich position. When taking off at high altitude airports where the density of the air is reduced, the mixture should be leaned in order to get the maximum power from the engine since an over-rich mixture results in loss of power. To lean the mixture prior to take-off, position the airplane at the end of the runway, lock the brakes and advance the throttle to full power. Adjust the mixture control by the method listed above to "rich best power".

At high manifold pressures, the mixture control should be set at full rich, except at very high altitudes, where leaning is necessary to get maximum power from the engine.

Below approximately 75 per cent of the rated rpm of the engine, it is generally permissible and recommended to use, at any altitude above 5000 feet, the mixture control as an economy device. The mixture control may be leaned to "lean best power" or lower at this time, depending upon the type of engine. Great care must be exercised, however, when using the mixture control as a fuel-economy device, because lean mixtures tend to increase engine operating temperatures.

This system of using the manually operated mixture control is, however, at best only approximate. The position of the mixture control should be re-checked with changes of operating condition, such as change in altitude, change in carburetor hot air setting, etc. (This method is not as effective with an engine having a constant speed propeller, since variation in mixture ratio will not appreciably alter the tachometer reading.)

More accurate methods of using the manual mixture control have made their appearance in recent years and are adaptable to most airplanes. These new systems are capable of providing a continuous instrument indication of the mixture ratio. These systems are of two main types: direct measurement and exhaust temperature measurement.

1. **Direct measurement.** A fuel flow gauge in the cockpit of the airplane tells the pilot the approximate gallons per hour of fuel being metered to the engine. The gauge is used in conjunction with tables, supplied by the manufacturer and found in the Airplane Operating Manual, which chart the normal fuel flow settings to use with certain rpm, manifold pressure and TAS and when flying at various altitudes and at various outside or carburetor air temperatures. Although some manufacturers have stated that it is possible to lean an engine by using the fuel flow gauge to indicate the amount of fuel being consumed per hour, the fact must be realized that this type of fuel flow measurement device is very likely to go out of calibration. Therefore, this type of instrument should not necessarily be relied upon to provide the degree of leaning accuracy required if acceptable safe temperatures within the cylinder are to be maintained.

2. **Exhaust temperature measurement.** The positive control of mixture is possible with the new EGT (exhaust gas temp-

erature) systems. The exhaust gas temperature varies as the air/fuel mixture is adjusted by the mixture control. It rises to a peak where the ideal mixture of air and gas is reached, and then begins to fall. By employing very sensitive probes, these temperatures are transmitted to an indicator in the cockpit. Where the EGT peaks (as the engine is leaned), the point of perfect air/gas balance is reached. At this point the fuel economy is greatest, but there is a slight loss of air speed. By increasing the richness enough to bring the EGT down to the best power EGT, a faster cruise is gained at a slight increase in fuel consumption.

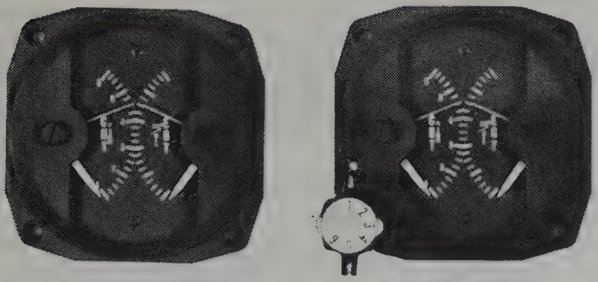


Fig. 17. Temperature gauges showing both exhaust gas temperature and cylinder head temperature.

Basic system **Analyser system.**

As shown in Fig. 17, there are 2 types of EGT gauges. The basic system obtains an exhaust temperature reading from one cylinder only (usually that one which, according to the engine manufacturer, runs the hottest). The analyser system incorporates a probe in each cylinder. Using the selector switch on the left, the pilot is able to check the exhaust temperatures in each cylinder, thereby assuring that when adjusting the mixture, temperatures will not be raised beyond the safety point in any one cylinder. An added advantage of the analyser system is the opportunity it affords to the pilot frequently to compare the running temperatures of each cylinder. If one is showing undue variance from the others, trouble may be indicated and a check and repair can be made before power loss or part failure occurs.

Incorrect mixture ratios will cause certain variations in engine performance. At worst, improper leaning has led to shortened engine life, poor engine performance, and occasionally even engine failure. Even when it is not responsible for such serious problems, improper leaning, at least, has deprived airplane owners of a tremendous amount of fuel economy.

The most common misuse of the mixture control by pilots is selection of too lean a ratio. Many pilots, in an effort to conserve fuel and get the most air miles per gallon, commit this error. A "too rich" mixture will cause loss of power, but only seldom results in complete engine failure. "Too lean" a mixture, however, causes overheating of the cylinder parts and, in many cases, will lead to complete engine failure and substantial damage.

Engines that are operated at too lean a mixture for a considerable period of time will undoubtedly sustain more wear and will cost more to overhaul than will those engines operated with correct mixture selection. Pilots should realize that, in the long run, it is usually far cheaper to use a little more fuel during the running time between overhauls than to pay the extra overhaul costs.

AUTOMATIC MIXTURE CONTROL

Some engines are fitted with a Mixture Control which **automatically** compensates for changes in the pressure and temperature of the air entering the carburetor. The device consists of a sealed bellows containing gas which expands and contracts with changes in pressure and temperature. The movement of the bellows is used to operate the Mixture Control Valve automatically. On some carburetors a single automatic control is provided. On other, the pilot may select "Automatic Rich" or "Automatic Lean". The former is used for take-off and when higher power is required. The latter is used to give the most economical fuel consumption at normal cruise power. Provision is sometimes made for both Manual and Automatic Mixture Control. In this case, the pilot will be able to select "Full Rich" and "Idle Cut-off" in addition to Auto-Rich and Auto-Lean.

WHY LEAN THE ENGINE

Proper leaning of the engine is both practical and economical and will result in:

1. Economy of fuel which means lower costs of operation.
2. A smoother running engine. Excessively rich mixtures make the engine run rough and cause vibrations which might cause damage to engine mounts and engine accessories.
3. A more efficient engine, giving higher indicated airspeeds and better airplane performance.
4. Extended range of the airplane at cruise.
5. Less spark plug fouling and longer life for spark plugs.
6. More desirable engine temperatures.
7. Cleaner combustion chambers and therefore less likelihood of pre-ignition from undesirable deposits.

CARBURETOR ICING

Under certain **moist** atmospheric conditions, with air temperatures ranging anywhere from approximately —5°C to 30°C, it is possible for ice to form in the induction system. This can pose serious problems for the pilot if he does not take action to rid the carburetor of this ice that is gradually closing off the flow of fuel to his engine. The fact that carburetor ice is responsible for a great many aviation accidents is perhaps indicative that many pilots, especially inexperienced ones, do not have sufficient respect for or appreciation of the ever present dangers of this icing problem. Such accidents can be prevented only by greater pilot awareness and vigilance.

Carburetor icing is usually indicated by a loss of power (drop in manifold pressure or in rpm) and, if severe enough, may cause complete engine failure, as the icing situation closes off entirely the induction flow.

TYPES OF CARBURETOR ICE

There are three types of carburetor ice.

Fuel Ice

Liquid gasoline must be changed into a vapour and mixed with air to become combustible. This process occurs in the carburetor. The heat that is required to change the liquid gasoline to a vapour is absorbed from the air that passes through the carburetor and into the manifold. The carburetor therefore is, in effect, a miniature refrigerator, the temperature in this mixing chamber dropping as much as 30 degrees Celsius below the temperature of the incoming air.

If this air contains large amounts of moisture (and most air contains some water vapour), the cooling process will cause the water vapour to condense and possibly freeze on all surfaces of the carburetor but especially on the throttle butterfly. It is possible for this "icing" condition to occur, as can be seen, with outside air temperatures as high as 30°C, in bright sunshine with no sign of rain. A temperature of around 15°C should be regarded as the most suspect. The minimum relative humidity generally necessary for icing to occur is 50%, with the icing hazard increasing as the humidity increases.

When atmospheric temperature is below − 5°C, the danger of carburetor icing is not serious, since the possibility of water vapour being present in air at such low temperatures is very slight. And any slight amounts of moisture that might be present in the air will be frozen and will pass through the system harmlessly.

Throttle Ice

Throttle ice is formed on the rear side of the throttle, especially when the latter is in a partially closed position. The rush of air across and around the throttle valve causes a low pressure, which has a cooling effect on the fuel/air mixture. Moisture in this low pressure area will freeze and collect on the throttle butterfly. The presence of even a small amount of ice may cause a relatively large reduction in airflow and therefore in engine power. A large collection will jam the throttle. The temperature drop resulting from this low pressure phenomenon is rarely more than 3 degrees Celsius. Therefore, throttle ice is not a problem when the ambient air temperature is above 4°C **if** only air passes the throttle as in a fuel injection system where the fuel is introduced downstream from the throttle.

When there is a fuel/air mixture at the throttle, any ice formation would be attributable to the cumulative effects of both the fuel ice and the throttle ice phenomena.

Impact Ice

Impact ice is formed either from water present in the atmosphere as snow, sleet or supercooled liquid or from liquid water which impinges on surfaces that are at a temperature below 0°C. Under these conditions, ice builds up on the air scoop, carburetor screen and carburetor metering elements.

PREVENTION OF CARBURETOR ICING

Modern airplane installations incorporate a means of directing heated air into the carburetor air intake. The Carburetor Hot Air handle on the panel activates this process. Many airplanes are fitted also with a Carburetor Mixture Temperature Gauge which tells the pilot the temperature of the mixture. Since it requires much more heat to melt ice that has already formed than to prevent its formation, the carburetor air temperature should at all times be maintained at 4°C to 7°C (40°F to 45°F) in flight by using carburetor heat. Some airplanes may be fitted with a Carburetor Air Inlet Temperature Gauge which measures the temperature of the air just before it enters the carburetor. In this case, the temperature should be maintained at 32°C (90°F).

For take-off, however, the carburetor heat control should always be in the Cold Air position, because the full power of the engine cannot be developed when the air is heated. Heated air has less density than colder air. Bring the carburetor air temperature within safe limits during run up, then select Cold Air for take-off. If icing conditions are suspected, Hot Air can be selected immediately after take-off. Since the full power of the engine is not required for cruising, moderate carburetor heat does not affect the performance of the engine in flight. Excessive carburetor heat, however, should be avoided when icing conditions are not present because detonation may result.

The possibility of ice formation may be detected (in airplanes that are without a Carburetor Air Temperature Gauge) by applying carburetor heat. If no ice is present, the application of heat will cause a loss of power indicated by a drop in manifold pressure or in rpm, in the case of an engine fitted with a fixed pitch prop. When ice has begun to form in the carburetor, the application of full heat will remove the ice and permit the rpm in time to return to normal, but **initially** it will cause a further loss of power and a short period of engine roughness. Heated air directed into the induction system melts the ice, which goes into the engine as water, causing some roughness and the additional power loss. As soon as the ice is melted and the resulting water eliminated, the manifold pressure or rpm will return to the normal setting. This should occur in a minute or so. It is necessary for the pilot to understand what is happening so that he will not be frightened out of using heat by what he might consider a situation that has been worsened. Not to use heat in such a circumstance could result in losing the engine completely.

With experience, a pilot learns to recognize atmospheric conditions under which carburetor icing might occur. In an airplane fitted with a Carburetor Temperature Gauge, he will prevent its formation by keeping the temperature of the air in the carburetor mixing chamber above the freezing level. A pilot, flying an airplane with no Carburetor Temperature Gauge of any sort, is well advised to check for carburetor ice by applying carburetor heat periodically. Certainly, it is preferable to anticipate the formation of carburetor ice and use heat as an anti-icer rather than to rely on it only as a de-icer. Any carburetor ice condition means loss of power; the engine exhaust therefore is not as hot; the carburetor hot air flow which is heated by passing around the exhaust pipes is not as hot and is, in consequence, not as effective in melting a build up of ice, especially if it is forming rapidly.

How long should the use of heat be continued when icing conditions are proven to exist? If icing is severe, then heat should be used as long as the flight continues. Despite the moderate power loss, no amount of heat can damage an engine running at a **cruise** setting of 75% power or less. The possibility of detonation in the use of heat occurs only when the engine is running at high rpm's such as during take-off and climb. During icing conditions, the pilot's concern is keeping the engine running, not the possibility of detonation.

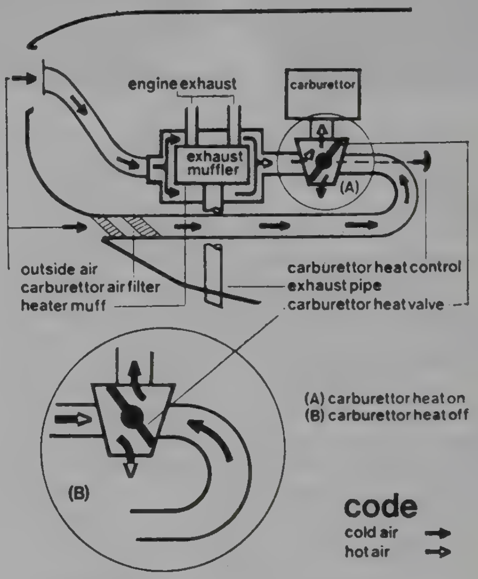


Fig. 18. Carburetor Heat System.

When using heat for extended periods, the mixture should be adjusted lean. Carburetor heat creates a richer mixture which may cause the engine to run rough. To correct this and also to compensate for the power loss when using heat, it is practical to adjust the mixture to a leaner setting.

Investigation of some forced landing incidents that were the result of carburetor icing have pointed up an interesting fact about this ever present hazard. One pilot using no carburetor heat but using a lean mixture experienced no carburetor icing. Another pilot, flying in the same air conditions, using no carburetor heat but flying at a full rich mixture developed ice and lost his engine. The refrigerator action from full rich mixture created enough difference in induction air temperature to bring on icing.

To make use of the carburetor heat system effectively, it is necessary to understand that the hot air that is directed into the carburetor by activating the carburetor heat control is cold air that is heated as it passes over the engine's exhaust pipes before it enters the carburetor air intake. The degree to which this air can be heated, therefore, is dependent on the heat of the exhaust. It can be readily appreciated, therefore, that it is of little value to apply carburetor hot air **after** the engine has been throttled back — an idling engine produces little heat in the exhaust, comparatively speaking, and the resultant hot air may be inadequate to thaw any ice in the carburetor. A rule to remember, therefore, is:

Always apply carburetor heat before reducing power.

If ice is suspected while flying at a low power setting, it may be necessary to open the throttle to produce more heat so that the hot air entering the carburetor will be sufficiently hot to thaw the ice.

It should be realized also that partial carburetor heat can be worse than none at all under certain conditions. If the fuel/air mixture temperature is in the −5°C range, with no heat applied, the formation of ice is not as probable as if the temperature were brought up to −1°C by the use of partial heat. At temperatures around −10°C, any entrained moisture becomes ice crystals which pass through the system harmlessly. Application of partial heat might cause carburetor icing by melting these crystals and raising the temperature to the icing range. In an airplane without a Carburetor Air Temperature Gauge, partial heat should never be used.

In fact, on many light airplanes, there is no **effective** partial carburetor hot air position. Therefore, the carburetor heat control should be used either in the "full cold" or the "full hot" position unless there is a carburetor mixture temperature gauge installed which would give a positive indication of the result of partial heat. If the hot air control is moved only to the half way mark, a situation is created where the cold air entering the front air scoop meets "head on" the carburetor hot air which enters from the other direction. There is little or no mixing before it enters the carburetor and the turbulence created may cause rough running. When "full cold" is selected, all the hot air is prevented by a valve from entering the carburetor and is diverted elsewhere. When "full hot" is selected, the same valve repositions itself to shut off completely the cold air so that only hot air enters the carburetor. (The design factors of the carburetor hot air control are such that a pilot should not assume that, by adjusting the control to a mark midway between the "full hot" and the "full cold" positions, he will obtain a mixture of 50% hot air and 50% cold air entering the carburetor.)

Awareness, therefore, of the possibility of icing conditions and a keen understanding of how ice affects engine operation are the pilot's best weapon against this hazard. Practising the following procedures may help prevent an accident due to carburetor icing.

1. Be sure the carburetor heat system and controls are in proper working condition.
2. Always start the engine with carburetor heat in the "Cold Air" position to avoid damage to the carburetor heat system.
3. Always, in the preflight check, include a check of carburetor heat availability and note the "on" power drop.
4. When relative humidity is high, use carburetor heat before take-off to clear any possible ice from the system. Do not use carburetor heat when taxiing. The cold air entering the carburetor by the regular intake is filtered, but the hot air is not. See Fig. 18.
5. In cold winter weather, Hot Air may be used for warm-up and taxiing prior to take-off. Extremely low temperatures cause the engine to run lean. Carburetor heat will enrich the mixture and help to vapourize the fuel. This procedure is recommended only in very cold weather, however, since the hot air that enters the carburetor is not filtered.
6. Use "Cold Air" selection for take-off.
7. Remain alert for indications of icing, especially when relative humidity is 50% or more or when visible moisture is present.
8. Regard any drop in power as an indication of carburetor icing and apply carburetor heat without making an adjustment in the throttle setting.
9. When flying in icing conditions, use at least 75% of power to obtain sufficient heat for the carburetor air heater. Maintain cylinder head temperatures as near maximum as possible.
10. Avoid clouds as much as possible.
11. Always apply full heat prior to closed throttled operations (e.g. descent) and leave on throughout throttled sequence. If the closed throttle operation is extended, open throttle periodically so that enough engine heat will be produced to heat the carburetor hot air sufficiently to prevent icing.
12. Remove carburetor heat in the event of a go-around. Always apply power first and then move the carburetor heat control to the cold position.

FUEL INJECTION

A Fuel Injection System dispenses with the carburetor and hence with the hazard of carburetor icing. Other advantages of fuel injection are:

1. More uniform distribution of fuel to all cylinders. The fuel is separately metered to each cylinder.

2. Better cooling, through the elimination of lean hot mixtures to some of the more distant cylinders.

3. Saving on fuel through more uniform distribution.

4. Increased power since the need to heat carburetor air is eliminated.

Fig. 19 is a schematic diagram of a fuel injection system that is typical of smaller aero-engines. The fuel is pumped from the **Fuel Tank** by the **Supply Pump** to the **Fuel Reservoir** at about twice the rate required by the engine. The surplus fuel is by-passed through the **Return Line** back to the fuel tank, but at a restricted rate that maintains the fuel in the reservoir under pressure. The by-pass eliminates any tendency to vapour lock while in operation.

The fuel passes from the reservoir through the **Metering Valve** to the **Fuel Injection Pump.** The Metering Valve controls the amount of fuel delivered to the fuel injection pump.

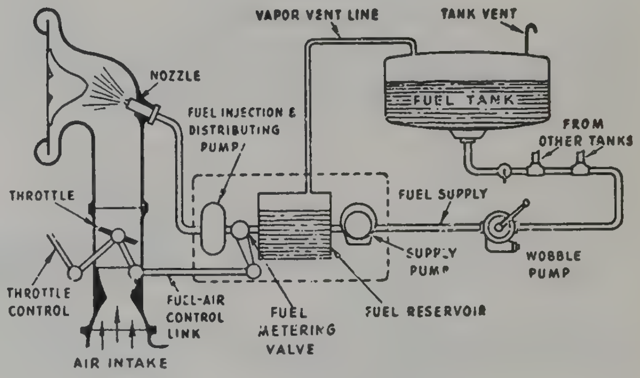


Fig. 19. Fuel Injection System.

The fuel injection pump delivers the fuel to the **Nozzles.** These atomize it into a fine spray which is discharged into the air stream entering the intake manifold.

The **Throttle** which controls the air intake is linked to the fuel metering valve. The fuel and air control units, so linked, are calibrated so that they automatically supply the correct mixture for any particular position of the throttle.

SUPERCHARGING

An engine designed to operate at normal sea level atmospheric pressure is called a **Normally Aspirated Engine**. As was pointed out in our discussion of the Mixture Control, as altitude increases, the density of the air decreases. If no adjustment is made for this condition, there will be loss of power as a result of an over-rich mixture.

The **Supercharger** is an internally driven compressor, powered directly from the engine. As much as 16% of the engine power can be required to drive the supercharger. It is installed downstream from the carburetor and compresses the fuel/air mixture after it leaves the carburetor. This is called **Forced Induction.**

Forced Induction may be used to increase the power, or "soup-up" an engine at low altitudes. In this case the pressure over and above sea level atmospheric pressure which is forced into the manifold is called **Boost.**

When Forced Induction is used at high altitudes to make up the deficiency in pressure due to the lower density of the air — and hence maintain sea level power — it is called **Supercharging.**

Superchargers can be classified as single-stage, two-stage or multi-stage depending on the number of times compression occurs. Superchargers can also operate at different speeds.

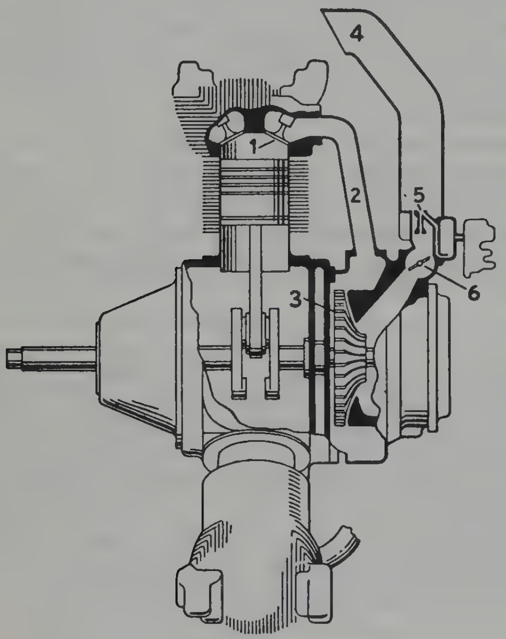


Fig. 20. The Supercharger.

The Supercharger compresses the mixture of air and gasoline, thus maintaining the charge at a specified weight for full power output at high altitudes. 1. Intake Valve. 2. Intake Manifold. 3. Supercharger. 4. Airscoop. 5. Carburetor. 6. Throttle.

All internally driven superchargers must include pressure and temperature sensing devices and the necessary units required to warm or cool the air. To produce good combustion in the engine cylinders, the temperature of the fuel/air mixture must be maintained within a certain range. It must be warm enough to ensure complete vaporization and not so hot that it reduces efficiency or causes detonation.

The pressure in the induction manifold is known as **Boost Pressure** and is indicated on a **Manifold Pressure Gauge,** which registers the **actual** manifold pressure at any time in **Inches of Mercury ("Hg.).**

TURBOCHARGING

In some airplanes, the supercharger is powered by the energy of the exhaust gases. This type is commonly referred to as a turbocharger system. The waste exhaust gases turn an impeller at high rpm. This in turn operates a turbine compressor. In this way, engine energy is used to maintain horsepower without using engine horsepower.

The turbocharger is installed between the air intake and the carburetor so that it compresses the air before it is mixed with the metered fuel in the carburetor.

The speed of the turbine depends on the difference in pressure between the exhaust gas and the outside air. The greater the difference, the less back pressure on the escaping exhaust gases and hence the higher the speed of the turbine and the greater the degree of compression provided by the turbocharger. As the plane climbs higher and higher into the area of less atmospheric pressure, the turbocharger, therefore, provides the engine with practically the same weight of air from sea level up to the critical altitude.

The turbocharger is usually designed to be operated only above a certain altitude, since maximum power without turbocharging is available below that altitude. It is automatically controlled by a pressure controller and requires no pilot action to activate its operation.

EXHAUST SYSTEM

The exhaust system of a reciprocating engine is basically a scavenging system that collects and disposes of the high temperature, noxious gases including the dangerous carbon monoxide that are discharged by the engine. Its main function is to prevent the escape of these potentially destructive gases into the airframe and cabin. Modern exhaust systems must resist high temperatures, corrosion and vibration.

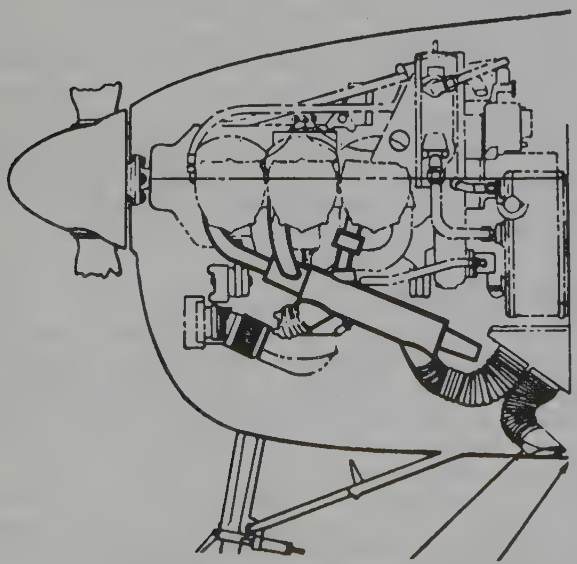


Fig. 21. Short Stack Exhaust System.

There are two main types of exhaust systems in use on reciprocating aircraft engines: the short stack system and the collector system. The former is used on non-supercharged engines and on low powered engines. It is relatively simple, consisting of a downstack from each cylinder, an exhaust collector tube on each side of the engine and an exhaust ejector on each side of the cowling. Shrouds encircle each collector tube. Outside air passing through one of these is heated by the high exhaust temperatures and carried to the cabin to provide cabin heat. The other carries heated air for the carburetor hot air system.

The collector system is used on most large engines and on all turbocharged engines. On the latter type of engine, the exhaust gases must be collected to drive the turbine compressor of the supercharger (see **Turbocharging**). In the collector system, a welded, corrosion resistant collector ring collects the exhaust from all the cylinders. An exhaust tailpipe carries the exhaust gases away.

Most exhaust systems are made of stainless steel which is known chemically as 18-8.

THE IGNITION SYSTEM

The function of the ignition system is to supply a spark to ignite the fuel/air mixture in the cylinders. The ignition system comprises two magnetos, two spark plugs in each cylinder, ignition leads and a magneto switch. The magneto operates on the principle of "the polarity of a magnet".

THE POLARITY OF A MAGNET

When a bar of iron is magnetized, it acquires a **North** and **South Pole**.

Unlike Poles attract. Like Poles repel. Hence the **Magnetic Lines of Force** in a magnet pass from S. to N. **inside** the magnet, and from N. to S. **outside** (Fig. 22).

The field in which these Magnetic Lines of Force lie around a magnet is called its **Magnetic Field.**

If the bar is bent into a horseshoe, the Lines of Force will flow in the same manner from S. to N. inside and N. to S. outside the magnet (Fig. 23).

If a soft iron bar is placed between the poles of a horseshoe magnet, the Lines of Force will flow through the bar (Fig. 24) because the iron offers 280 times less resistance than does air.

Magnetism and electricity are inseparable. If an electric current is passing through a conductor, a magnetic field will be set up around that conductor. If, on the other hand, a conductor is made to **cut** the lines of a Magnetic Field, an electric current will be **induced** in the conductor.

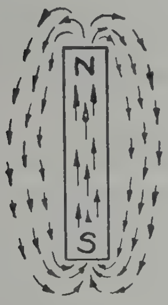


Fig. 22.

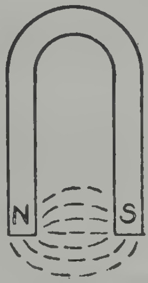


Fig. 23.

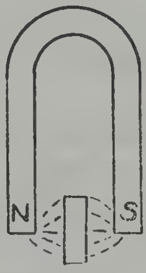


Fig. 24.

Imagine that the soft iron bar (Fig. 24) is rotating, so that it is continually cutting the lines of the magnetic field. Now, if a coil of wire is wound around a bar (so that the coil forms a closed circuit) a current will be **induced** in the coil while the bar is rotating. The current will reverse every half revolution of the bar as the latter passes opposite poles of the magnet, and is therefore known as an **Alternating Current.**

Here we have the primary element in what is known as the **Rotating Armature Type Magneto** — a horseshoe magnet with a rotating soft iron core, wound with a coil of wire, called the **Armature**, generating a low tension current by induction. In other types of magnetos the magnets rotate and the core is stationary. The principle, however, is the same.

THE MAGNETO

The complete Magneto combines all the elements of an entire ignition system; that is, it

1. Generates a low tension current as above,
2. Transforms this to high tension, and
3. Distributes the current to the individual spark plugs at the time it is desired to have them fire.

The elementary principle of the Rotating Armature Type Magneto is illustrated in Fig. 25.

The **Armature** revolves between the poles of the magnet, generating an **induced** low tension current in the **Primary Winding.**

The **Contact Breaker** is located in the Primary Circuit. With the breaker points of the Contact Breaker closed, the Primary Circuit is complete, and the Primary low tension current flows through the breaker points to **Ground.**

When the breaker points open, the flow of current in the Primary Winding is arrested. The magnetic field around the Primary Winding collapses, falling inward on itself and cutting the Secondary Winding. A **high tension** current is induced in the **Secondary Winding**, which consists of a coil of wire, lighter than the Primary, and wound around the latter in a ratio of about 60 turns to 1.

The high tension current is then led through a Collector Ring to the **Distributor**. The Distributor has a rotating arm which makes contact with separate segments as it rotates. Each segment is connected to an individual spark plug and distributes the current to the right plug at the exact time it is required to fire. (No. 3 in Fig. 25.)

The **Magneto Switch** is located on the instrument panel and operates in the Primary Circuit. When an engine is switched "off", the switch is closed. This means that the **Primary Circuit is directly grounded** and the breaker points cannot function. As long as the Switch remains open (or on "contact") the Primary Current will flow through the Contact Breaker which "makes" and "breaks" the Primary (by the opening and closing of the points) and so continuously induces a high tension current in the Secondary Circuit at each exact instant that this is required. At the same instant, the Distributor arm must be contacting the segment of the plug it is desired to fire.

The **Condensor** consists of alternate sheets of *mica* and *tinfoil*. It "soaks up" the induced current flowing in the Primary when the latter is abruptly arrested by the opening of the breaker points. In this way, it prevents the current jumping across the gap and so burning the points.

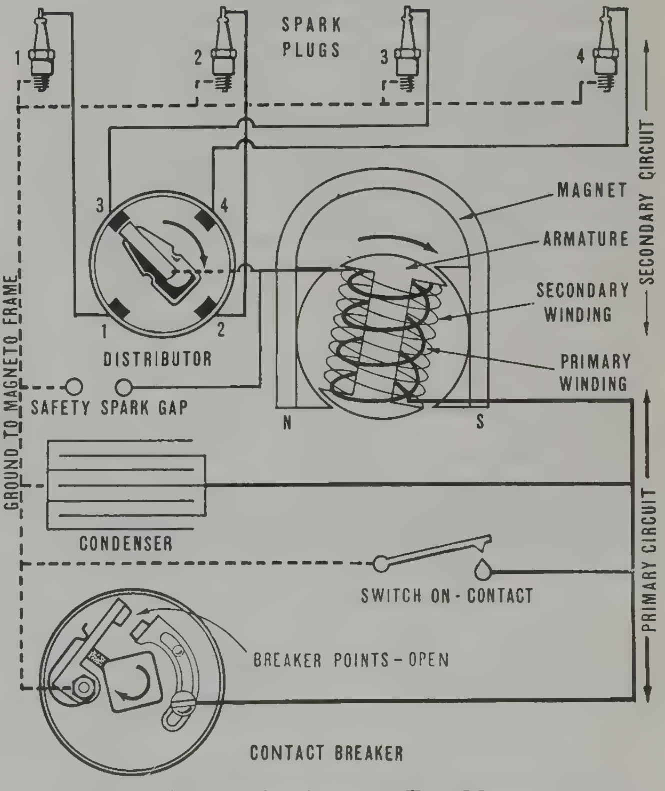


Fig. 25. Rotating Armature Type Magneto.

The **Safety Spark Gap** is located in the Secondary Circuit. An excessive voltage in the Secondary Circuit (usually due to a short circuit in the high tension lead) will jump the Safety Spark Gap and go to ground, thus preventing damage to the Armature.

Most light airplanes today are equipped with an **Impulse Coupling** which is fitted to one of the magnetos to facilitate starting. This is a mechanical device which permits the magneto to turn over fast regardless of how slowly the propeller and crankshaft are turning. The faster a magneto turns (up to a point), the hotter will be the spark it produces. An engine without such an impulse coupling may be difficult to start when it is cold because the slowly turning engine and the corresponding slowly turning magneto produce too weak a spark. The impulse magneto retards the spark somewhat to prevent propeller "kick back". For this reason, on those engines fitted with an impulse magneto, it is the practice to start the engine on the impulse magneto only. The "impulse" part of the magneto automatically disengages after the engine has reached normal idling speed.

Several modern piston engine airplanes use an auxiliary **"Hot Spark" Booster Coil** device to assist starting. This device obtains its power directly from the airplane battery and supplies an extra "hot spark" when the pilot presses the activating switch after the propeller starts to turn.

The reader should bear in mind that there are, from time to time, new types of ignition devices being designed and introduced onto the industrial market. Magnetos of new design may differ from that described above.

DUAL IGNITION

Modern aero engines are normally fitted with 2 spark plugs in each cylinder and 2 magnetos. One spark plug in each cylinder is fired by one magneto. The other magneto fires the other set of spark plugs. It is possible, therefore, to operate the engine on either magneto alone.

The purpose of dual ignition is two-fold.

1. Safety. If one system fails, the engine will still operate.
2. Performance. Improved combustion of the mixture increases the power output and gives better engine performance.

The Magneto Switch, which is located on the instrument panel, allows the pilot to select either or both of the magneto systems. It usually has a position to select the left magneto system, a position to select the right magneto system, a position to select both systems at once, and an "off" position. The engine should always be operated on both magneto systems during take-off and normal flight operations. After landing, the magneto switch should be turned "off" since the engine of a parked airplane can fire if the ignition switch is on and someone moves the propeller.

The failure of one magneto in a dual system will cause a loss in power of approximately 75 rpm at normal engine cruising power.

In the event of failure or partial failure of a magneto or of part of the ignition system (i.e. spark plug, high tension leads, etc.), rough running of the engine is bound to occur. In such a case, an engine will often run more smoothly if the ignition switch is selected to the "good" mag only. In the event that rough running or power loss occurs while in flight and if there is reason to suspect ignition malfunctioning, the pilot should try operating the engine on just one magneto at a time, by switching from the "both" position to "left" and then to "right", allowing the engine to operate for a few seconds on each position to ascertain on which position optimum engine operation and smoothness result. (Smoothness is a very important consideration since a rough running engine can set up vibration which, on some airplanes, could eventually cause engine mount failure.) Operating an engine in flight at normal cruise power on one mag will result in a power loss of about 3%. Provided the engine is running smoothly, no harm will be done to it if the pilot continues on to destination. However, it must be stressed that this is action to be taken if trouble develops in the magneto **during flight.** Certainly a single engine airplane would not attempt a take off on one magneto after observing a rough mag condition during ground runup.

SHIELDING

To prevent the ignition currents interfering with radio, the whole ignition system, magnetos, plugs, and wiring, are surrounded with a metal covering which is grounded. This is known as Shielding.

IGNITION TIMING

The spark on modern high speed engines occurs early to allow complete combustion and maximum pressure to be developed when the piston passes Top Dead Centre and is travelling down.

Ignition Timing means timing the magneto to fire at the right time.

THE ELECTRICAL SYSTEM

It is beyond the scope of this manual to discuss in full detail the electrical system of an airplane. However, very few modern airplanes are without such a system and since the pilot is required to use it, he should be familiar with its basic operation and purpose.

An airplane's electrical system includes everything that operates electrically with the exception of the magnetos which are driven by the engine for the sole purpose of producing current to the spark plugs. This ignition system is not connected with the airplane's electrical system.

In many modern airplanes, the electrical system supplies power, not only to start the airplane, but also to operate a multitude of controls, such as the flaps, undercarriage, all radios, lights, heater fans, anti-icing and de-icing equipment, windshield wipers, etc.

The basic electrical system of an airplane is not unlike that used in an automobile. It consists of a storage battery, master switch and battery solenoid, starter motor and solenoid, generator (or alternator), voltage regulator, bus bar and circuit breakers (or other types of fuses). On some airplanes, a separate generator switch may be incorporated.

The electrical system is usually either a 12 or a 24 volt system and, of course, is direct current. Most light airplanes use the 12 volt system.

Electrical energy is supplied by the **Storage Battery**. To complete the circuit between the battery and the electrical system, a battery **Solenoid** is incorporated which is activated by the **Master Switch**. (A solenoid is a switch of the artificial magnet type and is used because of its ability to operate as a remote-controlled device.)

The purpose of the **Starter Motor** is to turn the engine over so that it will commence to operate. The starter switch activates the starter solenoid which, in turn, permits current to enter and drive the starter motor (provided the master switch is turned "on").

The **Generator** (or alternator) is driven by the engine. Its purpose is 1) to supply current to the electrical system, and 2) to re-charge the battery. It begins to produce a current as soon as the engine rpm reaches a certain speed.

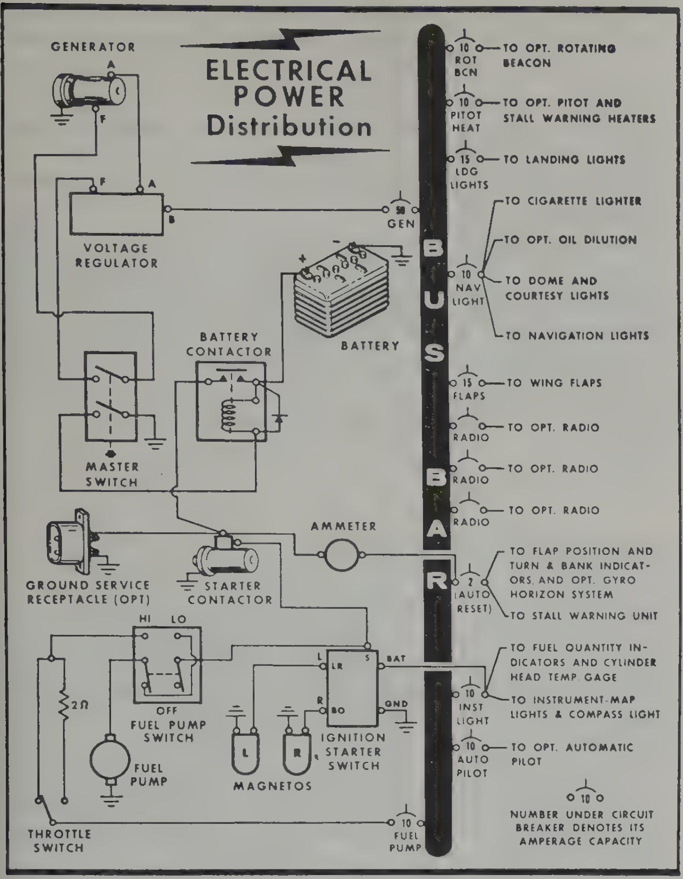


Fig. 26. An electrical system typical of a modern light airplane.

The **Voltage Regulator** 1) prevents the generator (or alternator) from over-loading the system, and 2) prevents the battery from becoming overcharged.

The **Bus Bar** receives the current produced by the generator (or alternator) and battery. It is from the bus bar that the current passes through the various circuit breakers and branches out to the various electrical circuits which are connected to the components that require electrical current to operate. These are the electrical turn and bank indicator, stall warning device, pitot heat, landing and navigation lights, cigar lighter, oil dilution system, fuel supply gauge, carburetor air temperature, exhaust temperature indicator, instrument and compass lights, cabin or dome lights, rotating beacon, radios, etc.

All electrical circuits are protected by **Circuit Breakers** or other types of fuses. These are incorporated into the system to protect the various components against damage caused by excess voltage or current, short-circuits, etc. Most circuit breakers are the "push to reset" type and every pilot should be familiar with their location in the cockpit and their operation in the airplane which he flies. It is not uncommon for an instrument or radio suddenly to go "dead" due to an electrical malfunction. A push on the "reset button", in such a case, may be all that is needed to make it operational again.

Most of an airplane's electrical components are automatically activated when the master switch is turned on. Those that are not (i.e., radio) should be left "off" until after the engine has been started. **Failure to follow this rule may result in damage to the component and will cause unnecessary drain on the battery.**

On modern airplanes, **Alternators** have replaced generators. The advantage of an alternator over a generator is that it produces sufficient current to operate the various electrical components **at low engine speeds** (i.e. taxiing) whereas a generator will not begin to supply an appreciable amount of current until the engine is turning at near cruising rpm.

In order for electrical components to function satisfactorily, the battery must be fully charged. In addition, the generator (or alternator) must be producing its rated current.

To ascertain that an airplane's electrical power source is functioning satisfactorily, the pilot may monitor an ammeter, voltmeter or generator warning light. These devices are usually mounted on or adjacent to the instrument panel. The **Ammeter** measures in amperes the rate of flow of the electrical current being produced. It also indicates when power is being used from the battery (it registers in the "discharging" range) as happens when the electrical components are turned on when the engine is not running. The **Voltmeter** indicates the voltage in the system. The **Generator Warning Light** indicates whether or not the generator is functioning. (An airplane fitted with a voltmeter or ammeter will not have a generator warning light. This warning light is usually installed in the absence of either of the other two instruments.)

For the most part, a pilot need only know that, for satisfactory electrical operation, the ammeter should always show on the plus (+) side of the "O" on the gauge regardless of the amount of current being used by the various components. An ammeter registering discharge or minus (−) indicates that electrical energy is being drawn from the battery rather than from the generator and, if this situation continues for long, it will result in a discharged battery and, possibly, insufficient current to operate the various components satisfactorily.

In modern airplanes and especially in those used for instrument flying, a great deal of reliance is vested in electrical systems and, although it may not be necessary for a pilot to know in detail the internal working of each component, he should at least have a general knowledge of how the system works, how to operate the components properly, what can go wrong and what he can do to correct a minor malfunction in flight.

The most important action a pilot can take in ensuring the proper functioning of the electrical system of his airplane is to ensure that the battery is always fully charged. This is especially important in an airplane equipped with an alternator, for, unlike a generator which will charge a low battery during a flight, an alternator will not bring a dead battery back to life. As a result, if the battery is down on an alternator equipped airplane, electrically operated equipment may not function properly.

THE PROPELLER

The function of the propeller is to convert the torque, or turning moment, of the crankshaft into thrust, or forward speed.

To do this, the propeller is so designed that as it rotates, it moves forward along a corkscrew or helical path. In so doing, it pushes air backward with the object of causing a reaction, or thrust, in the forward direction. Unlike the jet engine which moves a small mass of air backward at a relatively high speed, the propeller moves a large mass of air backward at a relatively slow speed.

The propeller blade is an airfoil section, similar to the airfoil section of a wing. As such, it meets the air at an angle of attack as it rotates and thus produces lift and drag, in the same way that the airfoil section of a wing does. In the case of the propeller, however, these forces are designated as **Thrust** and **Torque**. (Fig. 27)

Note: Propeller Torque is entirely different from Engine Crankshaft Torque. Propeller Torque is drag. It is the resistance to the blades as they rotate and results in a tendency in the airplane to roll in a direction opposite to the rotation of the propeller. Engine Crankshaft Torque, on the other hand, is the Turning Moment produced at the crankshaft. When the propeller is revolving at a constant rpm, Propeller Torque and Engine Torque will be exactly equal and opposite.

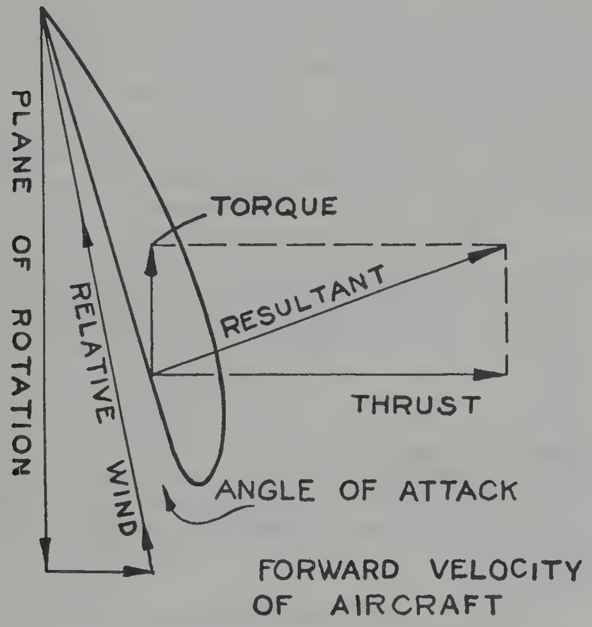


Fig. 27. Forces Acting on a Propeller Blade.

A quick look at a typical propeller will remind the reader that it tapers towards the tip and appears to twist. In effect, the airfoil section alters from the hub of the propeller to the tip and the angle of attack decreases. The tip of a propeller rotates in a larger arc than does the hub and therefore travels at a greater speed. To produce the same amount of lift, or thrust, all along the length of the propeller, the angle of attack at the tip does not need to be so great as at the propeller hub. As a result, by means of this variation in airfoil section and angle of attack, uniform thrust is maintained throughout most of the diameter of the propeller.

Propellers which are attached forward of the engine and which pull from the front of the airplane are called **tractors**. Those which are attached aft of the engine and push from behind are called **pushers**.

PITCH

The distance in feet a propeller travels forward in one revolution is called **Pitch**.

If the propeller were working in a perfect fluid, the distance it would travel forward in one revolution would be a theoretical distance dependent on the blade angle and diameter of the propeller. This is called the **Theoretical Pitch** or **Geometric Pitch**.

In a medium such as air, however, the propeller encounters lost motion and the distance it travels forward is somewhat less than its theoretical pitch. This lesser distance is called the **Practical Pitch** or **Effective Pitch**.

The difference between the Theoretical Pitch and Practical Pitch is called Propeller **Slip**.

The angle at which the blade is set (like the angle of incidence of a wing) governs the pitch. Hence, there is **Coarse Pitch**, meaning that the blade is set at a large angle, and **Fine Pitch**, meaning that the blade is set at a small angle.

A propeller set in **Coarse Pitch** will travel forward a greater distance with each revolution and hence the airplane will move forward at greater speed for a given rpm. In this way, it is much like the high gear in a motor car.

A Coarse Pitch propeller is best suited for high speed cruise and for high altitude flight.

Coarse Pitch is also sometimes known as High Pitch and as Decrease rpm.

A propeller set in **Fine Pitch**, on the other hand, will have less torque, or drag, and will consequently revolve at higher speed around its own axis, thereby enabling the engine to develop greater power, much as does the low gear in a motor car.

A Fine Pitch propeller gives the best performance during take-off and climb.

Fine Pitch is also sometimes known as Low Pitch and as Increase rpm.

TYPES OF PROPELLERS

FIXED PITCH PROPELLERS

Most training airplanes have fixed pitch propellers. The blade angles cannot be adjusted by the pilot. The angle of the blade is chosen by the manufacturer to give the best performance possible for all flight conditions, but at best it is a trade-off between take-off performance and cruise performance.

If a Coarse Pitch propeller is chosen, it will develop high cruising speed at comparatively low engine rpm with consequent good fuel economy. On the other hand, it will give poor take-off and climb performance.

If a Fine Pitch propeller is chosen, it will give good take-off and climb performance. However, a Fine Pitch propeller does not keep a good grip on the faster moving air in level flight, with the result that there is comparative inefficiency for cruising, both in the matter of speed and fuel economy.

VARIABLE PITCH PROPELLERS

To overcome the disadvantages of fixed pitch propellers, propellers whose blade angle, and consequent pitch, may be altered to meet varying conditions of flight have been developed.

Adjustable Pitch Propellers are those whose blade angle may be adjusted on the ground. They offer some advantage over the fixed pitch propeller in that the propeller pitch can be adjusted for varying flight situations. When operating at high altitude airports or when operating on floats when take-off and climb performance is critical, a Fine Pitch can be selected to give better performance for that particular type of operation. Like the fixed pitch propeller, however, the pitch cannot be altered during flight to select a better pitch angle for a changing flight condition.

Controllable Pitch Propellers are those whose blades can be adjusted by the pilot to various angles during flight.

Constant Speed Propellers are those whose blades automatically adjust themselves to maintain a constant rpm as set by the pilot.

The mechanism for varying the pitch of the propeller may be 1. Mechanical, 2. Hydraulic, or 3. Electrical.

Mechanical Variable Pitch Propellers

The mechanism by which the pilot can adjust this type of propeller is operated by a control on the instrument panel that is directly linked to the propeller. Stops set on the propeller govern the blade angle and travel.

Hydraulic Variable Pitch Propellers

In hydraulic variable pitch propellers, the basic method used to change the propeller pitch is a hydraulically operated cylinder that pushes or pulls on a cam connected to gears on the propeller blades. This cam action is somewhat similar to an automatic screwdriver — push the handle in and the screwdriver rotates the screw.

There are two types of hydraulic mechanism: counterweight and hydromatic.

A **controllable pitch propeller** operated by the counterweight principle relies on oil pressure to move the cylinder that twists the blades toward Fine Pitch. This oil is drawn from the engine oil pressure system. (Occasionally a gear pump is used to boost the engine oil pressure to ensure quick and positive action on the larger type propellers.) The oil which changes the pitch is controlled by a pilot valve, operated by a lever and linkage from the cockpit. The force which moves the blades the opposite way, towards Coarse Pitch, is Centrifugal Force, generated by the counterweights. With the controllable pitch propeller, the pilot selects either Coarse or Fine Pitch, depending on the flight attitude (cruise or climb), by means of the control in the cockpit that links to the pilot valve. The pitch of the propeller is then set in the selected pitch until the pilot elects to change it.

A **constant speed propeller** that operates by the counterweight mechanism uses the same oil pressure and counterweight principle to twist the blades toward the proper pitch angle to maintain a constant rpm. On the instrument panel, there are two power controls, a throttle and a propeller control. The throttle controls the power output of the engine which is registered on the manifold pressure gauge. The propeller control regulates the rpm of both the propeller and the engine. The desired rpm is set by the pilot. A propeller governor connected to the propeller control in the cockpit automatically changes the blade angle to counteract any tendency of the engine to vary from the setting. The governor is a device that consists of flyweights that are directly coupled to the engine and spin at engine speed. The governor operates the pilot valve which controls the flow of oil to the propeller. When the engine speed increases, centrifugal force causes the flyweights of the governor to fly outward, lifting the pilot valve and cutting off the supply of oil pressure to the propeller cylinder. This permits the counterweights to move the blades towards a coarser angle, thereby decreasing the engine rpm and automatically restoring the engine speed to the desired constant rpm. The reverse happens when an engine underspeed condition develops. Therefore, for any particular engine speed for any climb or cruise condition, the pilot merely selects the desired rpm. The constant speed propeller automatically maintains the proper blade angle required to keep the engine speed constant, regardless of the airspeed or altitude of the airplane.

Propellers, whether controllable pitch or constant speed, that operate on the counterweight principle, should be shifted to Coarse Pitch before the engine is stopped. This procedure protects the piston bearing surfaces (which are oily) from collecting foreign matter and also empties the propeller cylinder of oil which might otherwise congeal in cold weather.

When the engine is started, the propeller should be left in Coarse Pitch for about 1 minute. This action will allow the oil pressure to build up adequately and, in certain engines, will keep the engine master rod and bearings properly lubricated before the oil is allowed into the prop system. After about 1 minute, the prop may be shifted to Fine Pitch for warm up. Fine Pitch should be used for take-off and also for landing (in case maximum power is required to go around again).

The **hydromatic constant speed propeller** makes use of a powerful force called Centrifugal Twisting Moment which tends to turn the blades towards the Fine Pitch position. The use of this natural force eliminates the need for the counterweights. (Note the Centrifugal Twisting Moment moves the blades towards Fine Pitch, whereas the centrifugal force generated by the counterweights is used to move the blades towards Coarse Pitch.)

The hydromatic constant speed propeller uses a piston to twist the blades. Oil entering the piston chamber, or dome, under high pressure moves the piston aft and the propeller blades are moved into Coarse Pitch. Oil entering the piston at engine pressure assists the Centrifugal Turning Moment to move the blades towards Fine Pitch. The pilot valve, which is controlled by the governor, is a three way affair arranged to admit the high pressure oil to the piston that results in moving the blades towards Coarse Pitch, to close off the supply of oil thus holding the blade angle constant, and to admit the engine pressure oil to the piston that results in moving the blades back towards Fine Pitch.

With the hydromatic constant speed propeller, the engine should be started with the propeller in Fine Pitch. This reduces the load, or drag, on the propeller during starting and warm up.

Electrical Variable Pitch Propellers

An **electrical controllable pitch propeller** is operated by an electrical motor which turns the blades through a gear speed reducer and bevel gears. The governor is similar in principle to that used with the hydraulic propeller, except that the movement of the flyweights in this case opens and closes electric circuits. One circuit contains a field which causes right-hand rotation of the motor. The other contains a field which causes left-hand rotation. The direction of rotation of the motor moves the blades towards Fine Pitch or Coarse Pitch, whichever is required.

A two way switch enables the pilot to select either "Manual" or "Automatic" operation. In the "Manual" position, the propeller operates as a controllable pitch propeller. The pilot selects either Coarse or Fine Pitch. The blades remain fixed in that position until the pilot chooses to adjust them. Using the control on "Manual" reduces the current drain on the battery and reduces the wear on the control mechanism. In the "Automatic" position, the propeller operates as a constant speed propeller, the governor automatically holding the engine at the rpm selected by the propeller control in the cockpit.

FEATHERING

In multi-engined airplanes, when one engine is stopped, it is desirable to "feather" the propeller on the dead engine. Feathering means turning the blades to the extreme Coarse Pitch position, where they are "streamlined" and cease to turn. Feathering reduces the drag on the blades. It stops the propeller from "windmilling" and possibly causing damage to the defective engine. It also stops excessive vibration.

For feathering or unfeathering, an auxiliary oil pressure supply is required, since the engine is no longer running. This pressure is supplied by an Auxiliary, or Feathering, Pump operated by an electric motor. The auxiliary oil pressure is supplied to either face of the piston to move the blades towards "feather" or "unfeather", as the case may be, through the pilot valve system. A push-button **Feathering Switch** is operated manually by the pilot to feather or unfeather the propeller.

PROP REVERSING

It wasn't long before aviators wanted to use the power of their engines to stop their planes on the ground. This meant either reversing the engines or changing the pitch of the propellers. Reversing the pitch of a propeller is accomplished with the help of the auxiliary oil pump of the feathering system which assists the governor oil pump to twist the blades into reverse pitch.

To make propeller braking by reverse thrust as natural as possible to handle, an "instinctive" throttle quadrant arrangement is provided by the majority of airframe manufacturers. All throttle positions forward of the centre of the quadrant are for forward thrust operation. The rear section of the quadrant is the reverse range, and the further back the throttle is retarded, the more engine power is developed for reverse thrust. In general, the instinctive action taken by a pilot to turn a plane to the right is to retard the right throttle and advance the left. Similarly, when the props are in reverse, appropriate reverse thrust braking power is achieved by retarding the right throttle and advancing the left.

ENGINE INSTRUMENTS

THE OIL PRESSURE GAUGE

The Oil Pressure Gauge (Fig. 28) is one of the principle engine instruments and is usually located on the instrument panel with the Oil Temperature and the Fuel Gauges. It indicates the oil pressure supplied by the oil pump to lubricate the engine. The instrument is calibrated in lb. per sq. in.

The oil pressure which you read on the gauge is generally obtained at a point between the oil pump and a pressure regulating valve whose function is to maintain any desired working pressure, says 60 psi.

The Oil Pressure Gauge should be checked immediately after the engine has been started. If the oil pressure does not register within 10 seconds, the engine should be shut down and checked.

In starting an engine with cold oil in the system, the Oil Pressure Gauge will invariably read high, owing to the difficulty of forcing the sluggish oil through the small aperture in the pressure regulating valve. As the oil warms up and the flow through the pressure regulator improves, the pressure gauge will record the pressure accurately. High oil pressure should cause no concern until the oil is allowed to warm up and reach its normal viscosity, which might require 15 minutes. For this reason, in winter, a longer period of time is necessary to warm up the engine prior to flight.

If, on the other hand, it remains high, the engine is not getting proper lubrication. High oil pressure will force oil into the combustion chamber. Here it will burn, causing a smoky exhaust and badly carboned piston heads, rings, valve seats, cylinder heads, etc.

Low pressure can cause more serious trouble still. If it is permitted to drop low enough, there will be no film of oil at all between the working surfaces of the engine and metal will be rubbing on metal — with such ruinous results as burned out main bearings, etc. Never let the oil pressure fall below the recommended minimum (which is roughly 40% of the maximum pressure at cruising power).

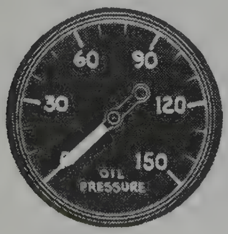


Fig. 28.
Oil Pressure Gauge.

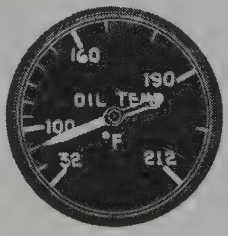


Fig. 29.
Oil Temperature Gauge.

THE OIL TEMPERATURE GAUGE

The Oil Temperature Gauge (Fig. 29) is normally located beside the Oil Pressure Gauge. It gives a reading of the temperature of the oil in degrees Fahrenheit or Celsius.

There is an intimate relationship between the oil temperature and oil pressure, due to changes in the viscosity of oil which temperature changes effect.

In starting the engine with cold oil, when the pressure gauge reads high, the Oil Temperature Gauge will read correspondingly low. As the oil warms up, both instruments will approach their normal readings at about the same rate.

An abnormal drop in oil pressure and coincident rise in oil temperature is a sure sign of trouble. However, even when the pressure shows no marked rise or fall, increasing oil temperature is a warning of excessive friction or overload in the engine.

Extremely low oil temperature is undesirable. Cold oil does not circulate freely and may cause scoring of the engine parts. Low temperature would be accompanied by a corresponding rise in pressure.

It should always be remembered that oil, in addition to lubrication, acts as a coolant.

THE CYLINDER HEAD TEMPERATURE GAUGE

The Cylinder Head Temperature Gauge (Fig. 30) records the temperature of one (or more) of the engine cylinder heads. The instrument gives a reasonably good indication of the effectiveness of the engine cooling system. It should be monitored frequently during steep climbs to ensure sufficient cooling air is reaching the engine.

Extremely high cylinder head temperatures are an immediate sign of engine overloading. High head temperatures decrease the strength of metals and result in detonation, pre-ignition and eventual engine failure.

When operating the engine on lean mixture, the maximum cylinder head temperature permissible is lower than when operating on rich mixture. The engine manufacturer's recommended limits should be strictly observed.

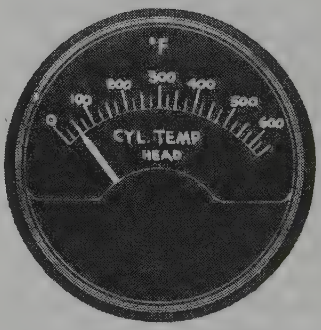


Fig. 30. Cylinder Head Temperature Gauge.

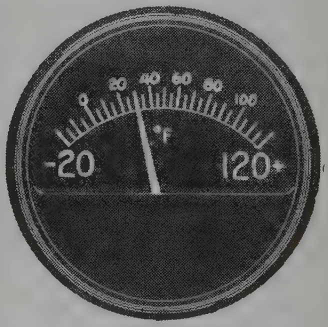


Fig. 31. Carburetor Air Temperature Gauge.

THE CARBURETOR AIR TEMPERATURE GAUGE

The Carburetor Air Temperature Gauge (Fig. 31) may be installed to indicate the temperature of the mixture entering the manifold, or it may record the temperature of the intake air entering the carburetor. Its purpose is to enable the pilot to maintain a temperature that will assure maximum operating efficiency and warn him of icing conditions in the carburetor that may lead to engine failure.

The Carburetor Air Temperature Gauge is, of course, the pilot's guide to the operation of the carburetor air heat control unit. Hot air is selected on or off to keep the mixture temperature, or intake air temperature, within the recommended limits.

If the instrument is installed to record the mixture temperature, this should be maintained at around 4°C to 7°C (40° to 45°F). If it is installed to record the intake air temperature, this should be maintained at about 29°C to 32°C (85°F to 90°F) when icing conditions exist.

THE OUTSIDE AIR TEMPERATURE GAUGE

The Outside Air Temperature Gauge records the ambient air temperature, that is, the temperature of the free air surrounding the airplane. To ensure that the temperature recorded is true, the element is shielded from the sun's radiation and located in a portion of the airflow that is relatively undisturbed. The temperature recorded by the gauge enables the pilot to select the proper manifold pressure, to calculate the true airspeed and altitude and it warns him of conditions that may cause ice formation.

THE TACHOMETER

The Tachometer, or RPM Indicator, (Fig. 32) is an instrument which shows the speed at which the engine crankshaft is turning in hundreds of revolutions per minute. The instrument usually incorporates a recording mechanism that keeps an accurate record of the engine hours.

Tachometers are of many types, the more common being (1) Mechanical — either Centrifugal or Magnetic and (2) Electrical — either direct or alternating current.

The rpm is directly proportional to the power output of the engine. 2000 rpm therefore represents twice the power developed at 1000 rpm (up to certain limits where the mean piston speed reaches something like 1500 feet per min. and the volumetric efficiency of the engine falls off).

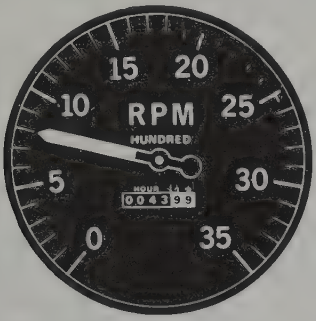


Fig. 32. The Tachometer.

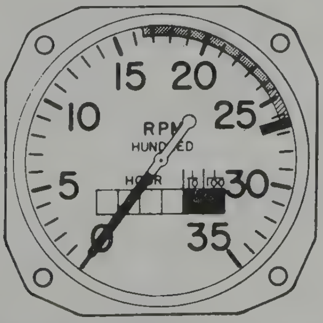
On an airplane fitted with a fixed pitch propeller, the Tachometer is the only instrument on the instrument panel that displays information about engine power settings. The rpm settings, as recorded on the Tachometer, are controlled by the throttle.

On an airplane fitted with a controllable pitch or a constant speed propeller, there are two instruments, the Tachometer and the Manifold Pressure Gauge, which display engine power information. In this case, the rpm settings, recorded on the Tachometer, are controlled by the propeller control. Manifold pressure settings are controlled by the throttle.

TACHOMETER MARKINGS

The Tachometer is colour coded to give a ready indication of the proper range of engine operation. The green arc indicates the normal range of operation. Rpm settings within this range should be used for continuous operations. The yellow arc indicates the caution range in which there is a possibility of engine damage under certain conditions. The red line is the maximum limit.

Operation of the engine at greater speeds than those recommended may result in excessive mechanical stresses and may cause failure of major engine parts.



▩ Green (Normal Operating Range)
▨ Yellow (Caution Range)
■ Red (Maximum Allowable)

Fig. 33. Tachometer Markings.

THE MANIFOLD PRESSURE GAUGE

On an airplane fitted with a controllable pitch or a constant speed propeller, there are two instruments which indicate information about engine power output, the Tachometer and the Manifold Pressure Gauge. Settings on the Manifold Pressure Gauge are controlled by the throttle.

Colour range markings, similar to those on the Tachometer, are incorporated on the dial of the Manifold Pressure Gauge to indicate the normal operating range and operation limits.

The instrument is usually located on the instrument panel adjacent to the Tachometer so that the pilot can refer to both instruments when making power settings.

The Manifold Pressure Gauge indicates in inches of mercury the pressure of the fuel/air mixture in the engine intake manifold at a point between the carburetor and the cylinders. A manifold reading of 26'' Hg indicates a pressure of about 13 pounds per square inch (psi) in the engine intake manifold (14.7 psi is equivalent to 29.92'' Hg).

On an airplane fitted with a constant speed propeller, the rpm setting will remain constant since the propeller automatically changes its pitch to maintain the desired engine speed. The Manifold Pressure Gauge therefore is the only instrument that records fluctuations in the engine power output. It is therefore important for determining proper throttle settings and it is the instrument which will indicate power loss from occurrences such as the accretion of carburetor ice.

When the engine is not running, the reading on the Manifold Pressure Gauge will be that of the existing atmospheric pressure. When the engine is running, the pressure inside the intake manifold is lower than that of the outside atmospheric pressure because the pistons create a partial vacuum.

The Manifold Pressure Gauge is also an important instrument in an airplane with a supercharged engine. Supercharging is accomplished either by increasing the pressure of the air entering the carburetor or, more commonly, by increasing the pressure of the fuel/air mixture after it leaves the carburetor. The pilot, in order to control supercharging, must know the pressure of the air, or of the fuel/air mixture leaving the supercharger. The Manifold Pressure Gauge gives him this information. On a supercharged engine, the pressure inside the intake manifold is higher than the outside atmospheric pressure and readings will normally be higher than those on non-supercharged engines.

A drop in the reading of the Manifold Pressure Gauge should be viewed as an indication of carburetor ice. If ice is forming in the carburetor, the airflow is restricted, causing a decrease in pressure in the intake manifold which will be indicated on the Manifold Pressure Gauge.

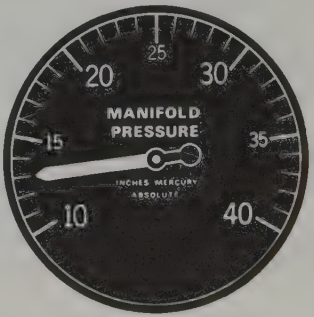


Fig. 34. Manifold Pressure Gauge.

Since the power of engines which are fitted with controllable or constant speed propellers and superchargers may be increased by either (a) increasing the rpm or (b) increasing the pressure, both of which are variables, it follows that there is an intimate relationship between the Tachometer and the Manifold Pressure Gauge.

If the rpm and manifold pressure of an engine at any given altitude are known, and the temperature correction for altitude applied, the brake horsepower of the engine can be determined from a chart. Reversing the process, an engine may be operated up to its critical altitude at any power desired by maintaining a specified boost and rpm. Some engine manufacturers recommend higher rpm and lower boost while others recommend lower rpm and higher boost to obtain a given power. These factors are governed by the design of each particular engine. It is therefore most important that the recommended power settings for any particular engine, for each specified condition, be strictly adhered to. These are usually stated on a placard placed somewhere within the cockpit.

Excessive manifold pressure raises the compression pressure, resulting in high stresses on the pistons and cylinder assemblies. If the pressure exceeds the limit for which the octane rating of the fuel has been selected. detonation will result. Excessive pressure also produces excessive temperature, which may cause scoring of pistons, sticking rings, and burned out valves.

When the propeller pitch control is moved, during flight, from the Fine Pitch (high rpm) to the Coarse Pitch (low rpm) position, without an accompanying adjustment of the throttle, the Manifold Pressure Gauge will register an increase, and, in the reverse situation (from Coarse to Fine Pitch), it will register a decrease. The Manifold Pressure Gauge registers a reading that is taken inside the intake manifold. When the rpm is decreased, the engine turns more slowly. The speed of flow of the fuel/air mixture through the manifold system is decreased. When the speed is decreased, the pressure increases (Bernouilli's theorem). Hence, the increased reading on the Manifold Pressure Gauge. The same situation in reverse occurs when the rpm is increased (from Coarse to Fine pitch). The engine speeds up, the fuel/air mixture speeds up passing through the manifold system, the pressure decreases and there is a decreased reading on the gauge.

When increasing power, increase the rpm first, and then the manifold pressure.

When decreasing power, decrease the manifold pressure first, and then the rpm.

MANIFOLD PRESSURE AS AN INDEX TO POWER

In the era when there was nothing but the fixed pitch propeller, a pilot was able to understand the operation of his piston airplane engine much more readily than is the case today with the more complicated variable-pitch constant-speed propellers. With a fixed pitch propeller, opening the throttle increases the manifold pressure and, of necessity, also the rpm. The power that an engine with a fixed pitch prop is producing is determined by reference to a Tachometer. The manifold pressure cannot be developed independently of the rpm. For each throttle setting, or manifold pressure setting, there is a corresponding rpm or BHP of the engine.

However, with the variable-pitch constant-speed propeller, opening the throttle will not change the rpm, but it will increase the manifold pressure, propeller load and horsepower. It follows, therefore, that the power absorbed by this type of propeller is independent of the rpm, for by varying the pitch of the blades, the air resistance and the propeller load can be changed while the propeller speed remains constant.

The process by which the propeller load or torque, as it is more properly called, is absorbed by the propeller is by varying the pressure acting on the piston. Any factor which affects the pressure acting on the pistons changes the torque. All other factors being equal (i.e., mixture ratio, temperature, type of fuel used), the pressure developed in the cylinders will depend on the mass of the charge that can be forced into it. This, in turn, will depend on the pressure existing at the intake valve ports and is measured by manifold pressure (MP). Thus torque (propeller load) turns out to be a function of manifold pressure.

Consequently, with variable pitch propellers, a given propeller load may be absorbed at an infinite number of rpm and, since power is a function of both MP and rpm, a particular horsepower (BHP) may be developed at an unlimited number of combinations of MP and rpm.

There are other variable factors affecting engine power of which the pilot must be aware if he is to operate his airplane engine efficiently. 1) The most important factor affecting power output is the fuel-air ratio. Variations in fuel flows from standard carburetor settings may reasonably affect power by a factor as high as 8 per cent. 2) Inlet air temperatures affect the air density of the charge in the intake manifolds. As all conventional power charts are based on the assumption that "standard temperature conditions" prevail at the carburetor inlet, a correction must be applied to the airplane performance charts and tables. A conventional "rule of thumb" for making this correction is to add 1 per cent for each 6°C below standard to the chart BHP; or to subtract 1 per cent for each 6°C above standard.

In summing up, therefore, we see that in order to determine what percentage of BHP is being developed from an engine having a variable pitch propeller, we need to know the rpm, MP, mixture setting (rich or lean) and temperature of the air entering the carburetor. Knowing these variables and by reference to the airplane manufacturer's tables or graphs, the pilot is able to calculate BHP and fuel consumption and is able to anticipate airplane performance.

HUMIDITY AND POWER

Factors such as outside temperature and altitude have an important effect on the power output of an airplane engine. Does humidity have any effect? Yes, it does, but only to the extent of about a 2% change.

Water vapour in the air will reduce the performance of an engine to a slight degree. The water vapour in the fuel/air mixture that is metered into the engine cylinders is incombustible. Therefore, it follows that the fuel to air ratio is increased and the engine operates as on a somewhat richer mixture. The result is some power loss and incomplete combustion.

For the most part, this power loss is so negligible that it need not be considered. Testing has indicated a loss of less than 2% for 100% relative humidity at temperatures of 32°C. The only occasion when the effect of humidity might be considered is during take-off and landing in marginal conditions, as on a very hot day when the humidity is high and the airplane is heavily loaded. On such occasions, that 2% change might be worth remembering in calculating the take-off run and climb the airplane will require.

OPERATION OF THE ENGINE

IMPORTANT CONSIDERATIONS ABOUT ENGINE OPERATION

Never make abrupt movements of the throttle. Such action can lead to damage and eventual engine failure.

On take-off, open throttle **slowly** to take-off power. Once climbing speed is reached, reduce power **slowly** and always climb at the highest indicated airspeed that is consistent with safety and other considerations of the flight. At the higher climbing speed, the engine will receive better cooling which is essential at a time when higher power is being produced (climbing power). Also during climb, use a rich mixture to benefit from the cooling effect on the combustion chamber of the evaporating extra fuel. Where installed, cowl flaps should be in the full open position for the take-off and climb.

Avoid high speed dives with engine idling. This kind of action will cause sudden cooling and could cause engine damage, specifically cracks in the cylinder heads around the spark plugs or valve ports. In the operation of any engine, cracked cylinders indicate that the pilot has been operating the engine at a fairly high temperature and then abruptly reducing power and thereby suddenly cooling the cylinder head. Gradual "let-down" without appreciably reducing engine power is best for the engine and is most efficient from the standpoint of obtaining maximum "air miles per gallon" performance.

Avoid long run-ups that overheat the engine. The streamlined and close fitting cowlings of today's general aviation airplanes restrict the flow of cooling air over the engine during ground maneuvring. Over lengthy ground operation may overheat the cylinders which will then be suddenly cooled by the rush of cool air after take-off. The time to taxi from the ramp to the runway is usually sufficient to bring the engine up to its normal operating temperature. In the event that overheating does occur, turn the airplane into wind, ensure that all cowl flaps are open to their full extent and run the engine at about 1000 rpm to allow the propeller to direct cooling air back over the engine.

Always use the power settings recommended by the manufacturer for cruise. Never over lean the mixture. Always double check that the method being used to lean the mixture is reliable.

The "Normal Rpm" stated by the engine manufacturer should never be exceeded for more than 5 minutes—and then only when absolutely essential.

The "Maximum Permissible Rpm" should never be exceeded more than momentarily in emergencies.

The best cruise power setting is one at which the engine runs the most smoothly at approximately the rpm or MP recommended by the manufacturer (or at which the propeller load curve intersects the engine power curve, if these are available for the engine being operated). When selecting certain rpm/MP power combinations, a pilot should always "go by the book". Some engines are designed to cruise at 1600 rpm and 26" MP, while other engines are designed to be operated at 2600 rpm and 23" MP. Concerning rpm/MP combinations, there is no "rule of thumb" that applies to all engines. The manufacturer's performance charts or tables must always be referred to for every model of airplane. When given a choice of different power settings (various combinations of rpm and MP), always use the one that produces the least noise and least vibration. This action will prolong engine life, decrease likelihood of damage or failure of parts or components and be less fatiguing to crew and passengers.

With superchanged engines, the "Maximum Permissible Boost" must **never** be exceeded.

Boost pressures greater than "Rated Boost" are only permissible for 5 minutes at a time.

The life and dependability of an aero engine depend to an appreciable extent on the use or abuse the motor suffers at the hands of the pilot. The reason that some engines go their full time between overhauls while others do not can usually be credited to the care or lack of care by the pilot in handling the engine controls.

During a long descent in cold weather, apply sufficient power to keep the engine at normal operating temperature.

Above all, never switch off an overheated engine. After taxiing in, allow it to idle a sufficient time to cool off. A lot of residual heat has to dissipate.

If the engine is fitted with Idle Cut-off, this should always be used to stop the engine.

MAINTENANCE AND CARE OF THE ENGINE

Airplanes should be flown frequently in order to prevent rust and corrosion from occurring inside the cylinders. Without frequent flights, water and acids collect in an engine. These are normally cooked out during flight. It is not sufficient, however, just to run up the engine on the ground in order to prevent this rusting process. If the oil temperature is not brought up to 75°C (165°F), water from combustion will be added to the engine oil. At 75°C (165°F), water is still a part of the combustion process, but the oil is hot enough to vapourize the water. If the oil temperature is not raised to 75°C (165°F), this water will build up and slowly turn to acid. If it is impossible to fly the airplane even around the circuit, the best thing would be to pull the propeller through a full turn to recoat the cylinders with a film of oil.

Change oil at intervals recommended by the manufacturer to avoid excessive engine wear. As the oil flows throughout the engine, it becomes contaminated with carbon particles, water, acid and dirt. The old oil should be drained when the engine is hot as the oil then flows more freely and there is better assurance that all the contaminated oil will be cleared out of the engine.

Installation of auxiliary oil filters are recommended to assist in preventing foreign matters from circulating through the engine and causing excessive wear.

Service spark plugs regularly and replace them when they are worn to their limits.

Inspect the ignition harness regularly to assure against worn insulation and seals that would cause misfiring.

Have the magneto points and timing checked as recommended by the manufacturer and have a compression check run regularly.

Check the intake manifold periodically to be sure there are no loose connections.

Air inlet filter screens should be cleaned regularly so they can perform their function of keeping sand and dust from entering the induction system.

CARE OF THE PROPELLER

Propellers should be checked regularly for damage. Failures of propellers almost always occur as the result of fatigue cracks which started at mechanically formed dents. Even a small defect such as a nick or dent if left unrepaired may develop into a crack. The crack, in turn, under great stress, will grow and blade failure is inevitable. Whenever defects are found, they should be repaired or the propeller replaced before further flight.

When performing an inspection on the propeller, inspect blades completely, not just the leading edge, for erosion, scratches, nicks and cracks. Regardless of how small the surface irregularity, it should be considered a source of fatigue failure. A visual inspection will sometimes miss small nicks and cuts that will be perceptible to the fingers. It is wise, therefore, to feel, with clean, dry hands, the entire surface of the blades.

Keep blades clean. A crack cannot be seen if it is covered with dirt or other foreign matter. As regularly as possible, wipe the blades with a clean cloth dampened with light oil. The oily cloth will remove substances that cause corrosion. Never hose down the propeller with water. Regular maintenance should include cleaning the propeller blades with a solvent and then waxing them with a paste wax.

Avoid engine run ups in areas containing loose rocks, gravel, etc.

Do not move the airplane by pushing or pulling on the propeller blades.

DO'S AND DON'T'S OF FUEL MANAGEMENT

Do be thoroughly familiar with your plane's fuel system and its operation.

Do know the engine's hourly fuel consumption rate.

Do check your fuel supply visually if possible.

Do visually check the fuel selector valve when changing tanks.

Do make sure, in aircraft with a fuel gauge indicator selector, to change both the indicator selector and the fuel valve selector in switching tanks.

Do check fuel selector valves before take-off in cold weather. It is possible for a fuel selector valve to freeze into position, making it impossible to select a fuel tank when needed.

Do learn how to use the mixture control properly.

Do make a check during preflight of fuselage and external wing surfaces for stains which may indicate fuel system leakage.

Do keep the tanks full when the aircraft is not in use. Water condenses on the walls of partially filled tanks and enters the fuel system.

Do periodically inspect and clean all fuel strainers.

Do practice good housekeeping in your routine maintenance.

Do exercise care in flight planning, taking into account any situation which would cause an increase in fuel consumption.

Do use only the fuel recommended by the engine manufacturer.

Do filter all fuel entering the tanks.

Do drain fuel sumps regularly on preflight checks.

Do assure that sump drains are fully closed after draining.

Don't fly beyond a refueling stop unless the amount of fuel remaining is more than enough to get you to your destination.

Don't overlean the mixture to practice false economy.

Don't use additives that have not been approved by the manufacturer.

Don't change the fuel selector just prior to take-off.

STARTING THE ENGINE

1. Position airplane so that dust will not be blown into hangars or on to other planes. In a strong wind, a light plane should be faced into wind for run-up, but not where it will blow dust on to other planes.

2. Parking brakes full on. Use chocks if parking brakes are inadequate to prevent the airplane from creeping forward during warm-up.

3. Before starting, the propeller should be pulled through several times by hand. This action releases any accumulation of oil in the combustion chambers and also assists in partially priming the engine. (Be sure the switches are OFF before pulling through.) The propeller must not be motored over on "Contact" until the pilot has had an "All clear" (thumbs up) signal from a ground crew mechanic.

When starting a seaplane at a buoy, a line should be placed loosely around one of the float undercarriage struts and not slipped until the pilot is sure that his engine will continue to run.

4. Carry out pre-starting procedures as per instruction manual or as previous experience dictates (i.e. certain amount of prime depending on whether the engine is hot or cold, mixture FULL RICH, fuel selector ON, carburetor heat on COLD, etc.). In most airplanes, the throttle should be set ¼" to ½" open from the full closed position prior to engaging the starter switch. Immediately that the engine starts, the throttle should be moved towards the closed position until the tachometer registers about 600 to 700 rpm and the engine should be allowed to run at this rpm until oil pressure is obtained.

The Oil Pressure Gauge should be checked immediately. If it does not register within 10 seconds, shut the engine down and investigate.

The action of throttling back immediately after starting the engine is very important to good engine handling. By doing so, engine wear is eliminated and friction reduced while the oil pressure is being built up within the engine. Secondly, in the event that chocks are not used and the brakes fail to hold, reducing the power immediately after the engine starts will prevent the airplane from rolling forward. On those airplanes that need to be started by "swinging" the propeller, reduction of throttle immediately after the engine starts is a safety precaution that prevents the airplane from rolling forward and seriously injuring the person who swung the propeller.

Selecting the exact throttle position prior to starting that will give 600 to 700 rpm is, in practice, difficult. Sometimes the setting will be accurate; sometimes it will produce an rpm of 1200 or more. Develop the habit of always closing the throttle slightly after the engine starts and then opening it until the rpm reaches the desired setting of about 700 rpm. Sometimes the engine may tend to "die" if the throttle has been closed too abruptly. Should this happen, the throttle should immediately be advanced sufficiently to keep the engine running.

After 1 minute of running in the 600 to 700 rpm range, the throttle should be adjusted as per the instruction manual to the recommended warm-up rpm which in most airplanes will be about 1000 rpm. At this rpm the engine is being warmed up gradually; there is some flow of cooling air being forced through the cowling by the propeller; and the engine oil pump is supplying adequate pressure to assure lubrication to all moving parts.

The airplane may be taxied to the take-off position during warm-up and, in fact, this procedure is recommended on all "tightly cowled" engines to eliminate excessive ground running of the engine as there is insufficient air flow through the engine (while the airplane is on the ground) for proper cooling. Ideally the engine warm-up should just be completed when the airplane reaches the take-off point and is in position for the pre-take-off check and engine run-up.

PROCEDURE FOR BACKFIRE DURING STARTING

Due to overpriming, raw gasoline often collects in the lowest point of the carburetor induction system and poses a fire threat in the event that a "backfire" should occur. A backfire, as the name implies, is the burning of the combustible mixture back through the intake manifold. It commences in the cylinder when, due to abnormal conditions (that exist in starting), there is still burning within the cylinder at the moment the intake valve opens to permit a fresh charge of fuel to enter. The fresh charge ignites and burns back through the intake pipes to the carburetor area where a pool of raw gasoline, if present, could ignite and explode.

In most cases, any fire resulting from a backfire can be quickly quenched by continuing to crank the engine since this action will suck the flames and explosive vapours into the cylinder where they will do no harm. (The advantage of a well charged battery can be readily appreciated. It could be disastrous if the battery went "dead" just when it was needed to turn over the engine to eliminate an engine fire.)

Another form of "backfire" is the exhaust manifold fire. In actual fact, it is not technically a "backfire" and is therefore incorrectly named. This also is caused by overpriming and occurs when raw gasoline that was introduced into the intake manifold system by the primer passes through the cylinder and into the exhaust manifold without being burnt. In this case, a pool of raw gasoline could collect in the exhaust system and could be set afire by the hot exhaust gases which may follow starting. In most cases, starting the engine quickly will smother the flames before they can spread and do any damage.

The fact may now be appreciated that most engine fires which occur at the time of starting result from improper technique in the use of the primer, throttle accelerator pump (which is the proper way to prime many engines) **or other priming devices.** Do not use the primer too far in advance of starting the engine. The fuel injected into the system gets more time to condense and run down the manifold to form a combustible pool somewhere in the system.

If an engine fire has started and it cannot be put out by getting the engine running, the fuel should be shut off and the primer locked and an external fire extinguisher or an extinguisher that is part of the engine installation should be used to put out the fire.

RUNNING UP THE ENGINE

The throttle should always be opened and closed **slowly**.

1. Check oil pressure and temperature. Switch off the engine immediately if the pressure or temperature appear abnormal.

2. Check the rpm at full throttle. Throttle back to the engine speed recommended for a magneto check. Cut the switches one at a time to test each individual magneto, by moving the switch from BOTH to RIGHT, to BOTH, to LEFT, and back to BOTH. (You return to BOTH each time to allow the engine to regain its normal rpm and to clear the inoperative set of plugs in case they may have fouled with oil while their magneto switch was off). Move the switches to OFF *momentarily* to check for malfunctioning of the switch or ground connections. CAUTION: Conduct these checks as quickly as possible to prevent backfiring when the ignition is switched on. (If the engine continues to fire when the switch is OFF, shut off fuel and check magneto ground lead after the engine has stopped.) Check all instruments for proper indication while running up engine, i.e., voltmeter or ammeter, Manifold Pressure Gauge, fuel pressure, RPM Indicator, vacuum, etc.

3. If the engine is fitted with a controllable or constant speed propeller, test its operation by moving the lever to Coarse Pitch. See that the required drop in rpm occurs. Return lever to Fine Pitch after the test. Check propeller feathering operation, if applicable.

4. Test operation of the carburetor heat control by selecting "Warm Air". If the control is working satisfactorily, a drop in power will be noted. Check for operation of Carburetor Temperature Gauge, if fitted.

5. See that the primer pump is switched off or that the manual primer is off and locked. Check for correct operation of mixture control by moving it from full rich to full lean and back again. The engine should cut out when mixture control is placed in the full lean position on the ground.

6. Idle the engine for a few moments to check the idling speed at proper working temperature.

During the running up, the pilot should check and listen intently for any sign of engine trouble. A minor adjustment on the ground may forestall a serious situation due to engine failure on take-off or in flight.

Never attempt to take-off with a cold engine.

ENGINE OPERATION IN COLD WEATHER

Operation in winter requires more care on the part of the pilot and an understanding of the effect of cold on the component parts of the power plant.

In cold weather, taking off with a cold engine and cold oil can put you in the embarrassing position of coping with a loss of power during a critical part of the take-off procedure. Aviation lubricants are heavier than the commonly used automotive engine oils and therefore require more time in warm up to obtain normal flow to function properly throughout an aircooled airplane engine.

At temperatures above freezing, a warm up of 2 or 3 minutes at 1000 rpm may be sufficient to bring engine temperatures within operating range. At temperatures below freezing, the warm up should be longer. With turbocharged powerplants, even more time is required to assure proper controller operation and to prevent manifold pressure overboost.

Engines turn over rather sluggishly in cold weather and consequently there is a tendency to overprime to hasten the start. This practice may result in an excess of raw gasoline washing the oil from the cylinder walls, leaving them vulnerable to scoring by the piston. Excess fuel also increases the hazard of fire.

The use of an oil of a heavier weight viscosity than that recommended for the ambient temperature will tend in cold weather to prevent the normal operation of hydraulic lifters and thereby cause loss of power. It is good practice to use the weight of oil recommended by the engine manufacturer.

Avoid overboosting supercharged engines in cold weather take-offs. Cold air is heavier than air at a more moderate temperature and therefore power output of the engines is increased. For every 5 degrees Celsius below standard air temperature, engine power increases by 1%.

The engine doesn't start at sub zero temperatures? A common cause of this problem is moisture that has frozen on the spark plug electrodes. Remove at least one plug from each cylinder and warm them.

A battery that is not fully charged is apt to freeze at below freezing temperatures. If the airplane will not be used until the next day or for an even longer period, remove the battery and keep it in a warm place.

In very cold weather, preheating the engine from an auxiliary heating source is essential. Moisture frozen in some critical parts of the engine can cause engine damage during a cold start. When heating an engine by means of an external source, it is most important that a well insulated cowling cover be used to keep the heat within the engine thus assuring that it will warm all engine parts evenly.

ENGINE FAULT FINDING TABLE

1. ENGINE WILL NOT START.

No Spark at Plugs (plugs fouled or incorrectly set—H.T. leads crossed—switch "off" or defective switch—mag. ground wires broken or grounded—defective mag.—wet plugs, leads or mag).

Weak Spark (breaker points dirty or incorrectly set— faulty condenser).

Insufficient Fuel (tanks empty—fuel cocks "off"— insufficient priming—air vents in tanks clogged—leaks or stoppages in fuel system—defective fuel pump—float needle valve sticking—altitude control open—carburetor tuned too weak—vaporization of fuel in lines of fuel injection engine caused by hot engine).

Flooding (excessive priming — fuel pressure too high).

Cold Engine (engine stiff to turn).

Water or Dirt in Fuel.

Mechanical Defects (plugs loose—cylinders scored—piston rings stuck, broken or scored—loose intake connections—poor compression and leaky valves).

Insufficient Cranking Speed.

Incorrect Throttle Setting.

2. ENGINE MISSES.

Defective Plugs (oiled up, incorrectly set, or cracked).

Defective Magneto (timing incorrect).

Water or Dirt in Fuel Line.

Mechanical Defects (sticking valve—crack in cylinder).

Low Compression in One or More Cylinders.

Cold Engine or Overheated Engine.

Lack of Fuel (fuel tank vents clogged—fuel cock not fully open—lean mixture).

3. BACKFIRE.

Incorrect Timing (H.T. leads crossed—spark too far advanced).

Defective Carburetor (Sticking float, needle or toggles).

Lean Mixture (dirty filters—altitude control open—fuel pressure low — leaks in fuel system).

Water, Dirt or Air Lock (in carburetor or fuel line).

Sticking Valve.

Hot Engine (carbon in cylinders — overheated valves, plugs, etc.).

4. LOSS OF POWER

Defective Plugs (oiled up—incorrectly set).

Incorrect Timing (magnetos defective — not properly synchronized — faulty wiring — breaker points burned or pitted).

Insufficient Fuel (leaks or stoppages in the fuel system—defective fuel pump — float needle valve sticking — weak mixture—throttle or carburetor throttle valve not fully open—altitude control open—carburetor iced up).

Excessive Fuel (rich mixture—fuel pressure too high—air intake restricted).

Improper Lubrication (wrong grade of oil—incorrect oil temperature—leaks—low oil pressure—dirty filters).

Carburetor Heat Used Unnecessarily.

Carburetor Icing.

Excessive Cylinder Temperatures (engine tends to seize).

Loss of Compression (plugs loose—piston rings worn—valve seats worn—clearances out—springs weak—valves warped, stuck, or seating improperly—incorrect timing).

Poor Fuel (or water or dirt in fuel). **Pre-ignition.**
Engine Too Cold, or Overheating. **Internal Friction.**
Engine Needs Overhaul. **Detonation.**

5. **ROUGH RUNNING**

Propeller or Engine Bearers Loose or Out of Balance.
Bent Crankshaft. **Defective Plugs.**
Defective Magnetos (timing, wiring, etc.)
Incorrect Mixture (too rich or too lean).
Wrong Valve Clearance (or sticking valve).
Detonation, or Pre-ignition. **Cold Engine.**

6. **ENGINE STOPS.**

Lack of Fuel (tanks exhausted — gas cocks accidentally knocked closed—failure to switch over to full tank when the one in use runs dry—water or dirt in fuel—fuel tank air vents clogged—filters clogged—air lock in fuel system—mixture control accidentally moved to idle cut-off).

7. **ENGINE CONTINUES TO RUN WITH SWITCHES OFF.**

Defective Switch or Wiring. **Overheating.**
Pre-ignition.

8. **ENGINE WILL NOT TAKE THROTTLE.**

Lean Mixture. **Cold Engine.**

9. **BLUE SMOKE FROM EXHAUST.**

Worn or Stuck Piston Rings.

10. **BLACK SMOKE OR LONG RED FLAME FROM EXHAUST.**

Excessive Rich Mixture.

11. **ENGINE OVERHEATING.**

Detonation. **Stuck Rings.**
Insufficient Oil Supply. **Lean Mixture.**

12. **EXCESSIVE OIL CONSUMPTION.**

Blocked or Frozen Breather (causing excessive pressure).
Sticking Valves. **Worn Piston Rings.**

13. **LONG YELLOW FLAME FROM EXHAUST.**

Lean Mixture.

JET PROPULSION

It is **not** the blast of hot gases out the exhaust of a jet engine that provides the driving force, but rather the **reaction** to the exhaust jet. Jet propulsion is based on Sir Isaac Newton's Third Law of Motion, namely that every action will have an equal and opposite reaction. (Like the "kick" you get from a shotgun.)

Imagine a sphere (Fig. 35) suspended by a cord and filled with air under pressure. The sphere will remain motionless, because the pressure is exerted evenly against all sides. The pressure at A is balanced by the equal and opposite pressure at B. The pressure at C is balanced by equal and opposite pressure at D.

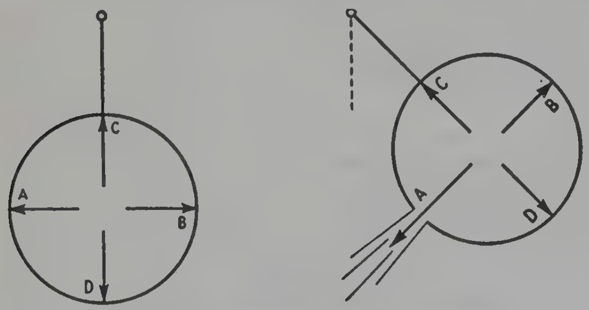


Fig. 35. Principle of Jet Propulsion.

Now punch a hole in the sphere allowing air to escape at A. The pressures at C and D are still equal and opposite. The pressure at B pushes the sphere forward. The force exerted at B is equal and opposite to the momentum of the air escaping at A. A is the Jet. B is the reaction to the jet, which is known as **Thrust**.

THE RAM JET

The simplest form of jet engine is the **Ram Jet**. This is little more than a streamlined "stove" in which fuel mixed with air is burned and exhausted out the "stovepipe" to produce a thrust reaction. The air which enters the Intake is "rammed" into the Combustion Chamber by the forward speed of the airplane. (Fig. 36). As this high speed ram air passes through the diffuser section, as indicated in Fig. 36, the speed of the air decreases while the pressure increases. This is brought about by the increase in cross section of the diffuser. (Bernouilli's Theorem for Incompressible Flow). The difference in pressure is known, in a Ram Jet engine, as the **Pressure Ratio**. (When we get to the Turbo-Jet engine, Pressure Ratio has a slightly different meaning).

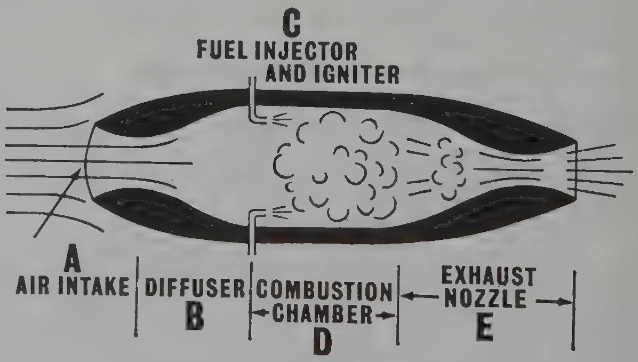


Fig. 36. Ram Jet Engine.

The slowed down ram air is mixed with fuel introduced by the Fuel Injectors at C. This volatile mixture of fuel and air — once ignited — burns, expands and roars out of the Exhaust Nozzle at tremendous velocity at E. This creates a **Thrust Reaction** similar to that which we observed in the case of the punctured balloon. The difference between the high pressure in the forward part of the engine and the low pressure towards the rear, imparts momentum to the jet stream rushing out of the nozzle. This momentum has its equal and opposite reaction in the form of thrust, the force which drives the engine ahead and propels the airplane forward.

Initially, the engine is started by a spark, or igniter plug, the same as a piston engine, but as soon as the fuel is ignited, the ignition is switched off and the fire burns continuously.

The Ram Jet is extremely simple and particularly suited to high altitude and high speed. First, however, it must be carried aloft by some other means of power and impelled at sufficient forward speed to enable it to get started. Its practical use appears limited to missiles, supersonic airplanes, etc.

THE TURBOJET ENGINE

In the Turbojet engine, the intake air is compressed and rammed into the combustion chamber by a Compressor, which is driven by a Turbine Wheel. The turbine in turn is driven by the momentum of the hot exhaust gases.

The basic principle of the turbojet engine, together with some of its construction features, are illustrated in Fig. 37, the cutaway drawing of the General Electric J-85 engine.

The engine is started by a starter motor. Air enters the **Air Inlet Duct** (1) past the **Inlet Guide Vanes** which guide the flow of air at the right angle to the first stage Compressor Rotor. The air is compressed by the **Compressor** (2). The Compressor illustrated has 8 rows of **Rotor Blades** one behind the other, axially, which rotate around a shaft, and is therefore referred to as an **Eight-Stage Axial Flow Compressor**. Between the rows of Rotor Blades are rows of stationary **Stator Vanes** (2a). They are fastened to the engine case and form a complete ring around the inside of the engine casing. Their purpose is to convert the velocity imparted by the rotor blades into pressure and to direct the air at the proper angle to the next set of blades where the process is repeated.

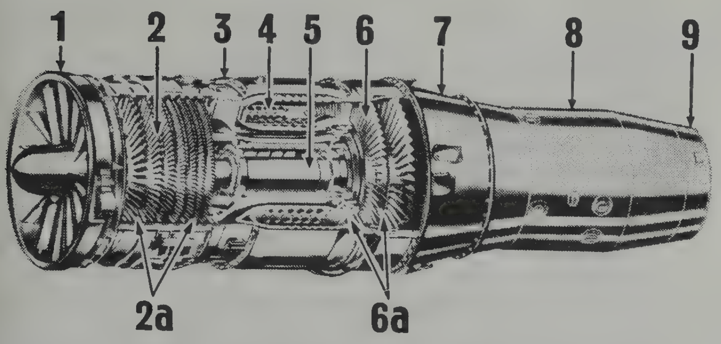


Fig. 37. General Electric J-85 Turbojet Engine.

The **Mainframe Section** (3) serves as the main structural component. In many turbojet type engines, the section behind the Compressor functions as a **Diffuser**.

The air from the Compressor enters the **Burner Section** (4) through holes in the burner skin. (These also help to reduce the intense heat of the burning gases.) The **Igniter Plug(s)** and **Fuel Nozzles**, located within the Burner Section, ignite the gases initially and admit the fuel which burns with the compressed air to produce terrific heat. The heated gases are allowed to drop in pressure and accelerate through rows of **Nozzle Guide Vanes**, the whole assembly of vanes being generally called the **Turbine Nozzle(s)**. Whereas in the compressor, the vanes convert velocity to pressure, in the turbine they convert pressure to velocity. The rotational velocity is arrested by the blades or buckets of the **Turbine Wheel** (6), thereby producing shaft horsepower to drive the compressor.

Because of the very high temperature of the gases entering the turbine, only a part of the pressure built up in the compressor is needed to make the turbine drive the compressor. That is, there is pressure left over after the turbines to make the gas do more work downstream.

The **Exhaust Cone** (7) collects and straightens the gas flow. The length of the **Exhaust Duct**, or **Tail Pipe** (8) determines the position of the **Exhaust Nozzle** (9), an orifice at the rear of the Duct, whose size determines the speed of the gases as they emerge from the engine. Increasing the speed of the gases increases their momentum and hence the amount of thrust produced by the engine.

The **Gas Generator** consists of the parts of the engine which produce gas at a higher pressure and temperature than at engine inlet. This includes the Compressor, Diffuser, the Burner and the Turbine. The term ''gas'' has nothing to do with gasoline. A Gas Turbine Engine is one which is operated by a gas, as distinct from one operated by steam vapor or water.

The engine is controlled by the amount of fuel fed to it. Cutting of the fuel stops the engine.

The fuel used is kerosene. Any hydrocarbon can be used in a jet engine as long as it can be blown through a nozzle and burned.

Why do some jet engines leave black smoke trails? Poor combustion.

The fuels used in gas turbine engines consist almost entirely of hydrocarbons—that is, compounds of hydrogen and carbon. When the fuel is burned, the hydrogen and carbon combine to form, ideally, water and carbon dioxide. If, however, the combustion is not complete, particles of carbon are formed which are visible as black smoke.

The engine is lubricated by a pressure spray or flow of oil which is fed to the three bearing assemblies. Synthetic oil is the type most widely used on turbojet engines.

Temperatures in the combustion chambers and around the turbine in a jet engine run as high as 700°C.

Because of the heat of the jet stream, a person should not stand nearer than 150 to 200 feet directly back of the tailpipe.

The jet engine weighs roughly one quarter the weight of a piston engine and propeller of similar power output.

The frontal area of the axial flow jet engine is approximately one tenth that of a radial piston engine's frontal area.

The jet engine's power is rated in **pounds of static thrust** instead of horsepower. At a speed of 375 miles per hour, one lb. of thrust equals roughly one horsepower. At 600 mph at sea level, the Ghost engine's 5000 lb. of static thrust is equivalent to 8000 **true** thrust horsepower. Assuming 66% propeller efficiency for the piston engine, this would be equivalent to 12,000 hp.

Thrust is simply force measured in lb. (or Kilogrammes).

Like the piston engine, the jet engine's power depends upon the *weight* of air it can consume. As altitude increases, the density of the air, that is its **weight**, decreases. It is for this reason that superchargers are used to maintain the power of piston engines at altitude. The turbine engine also suffers from loss of power at altitude, but this is compensated for by the lower drag (resistance to forward speed) and the ''ram'' effect of the jet's higher speed, which rams more air into the engine to produce a ''supercharging'' effect.

The **Pressure Ratio** of a gas generator usually means the ratio of pressure at the compressor exit to that at the compressor inlet. Where the expression Engine Pressure Ratio (EPR) is used, it means the pumping pressure ratio of the whole gas generator, i.e. ratio of pressure at exit of the compressor drive turbine to the compressor inlet.

Pressure Ratios (of the compressor) at maximum rpm are mostly in the range 6 to 1 to 15 to 1. The EPR is usually 1.5 to 1 to 2 to 1.

TURBOSHAFT AND TURBOPROP ENGINES

In addition to jet propulsion, the gas turbine engine can also be used (in lieu of the reciprocating piston engine) to drive a propeller, in which case it is known as a **Turboprop** engine, or to drive a helicopter rotor, in which case it is known as a **Turboshaft** engine. One of the simplest of several different methods presently in use is the **Fixed Shaft** method. In this arrangement, the Turbine drives both the Compressor and the Shaft directly.

In some gas turbine engines two Turbines are used, one to drive the Compressor and the other to drive the Shaft. When these turbines are mechanically free of one another, the engine is called a **Free Turbine** engine. The Pratt and Whitney Aircraft of

Canada PT6 engine illustrated in Fig. 38 is an example of a Free Turbine Turboprop engine.

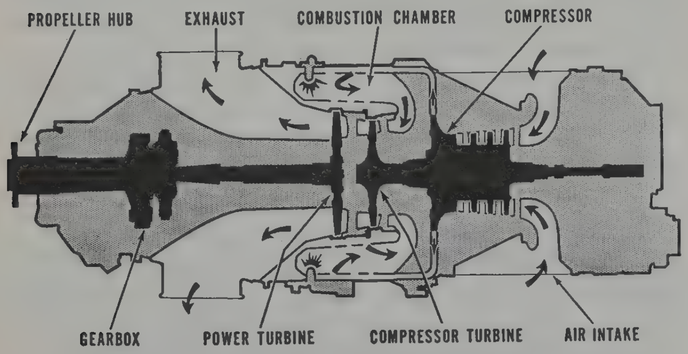


Fig. 38. PT6 Free Turbine Turboprop Engine.

The arrows indicate the gas flow through the PT6 engine. Air enters the Air Intake and is compressed by a Three Axial Stage and Single Centrifugal Stage Compressor before it enters the Combustion Chamber. The hot gases from the Combustion Chamber drive the Compressor Turbine. They then drive the separate Power Turbine, which in turn drives the Propeller Shaft. The Gear Box reduces the propeller speed to a fraction of the speed at which the turbine drives the drive shaft.

THE BY-PASS ENGINE

The propeller generates thrust by imparting a relatively small acceleration to a relatively large mass of air. The jet generates thrust by imparting a relatively large acceleration to a relatively small mass of air. For low air speeds, the propeller is most efficient. For high air speed, the jet excels because the jet engine produces its greatest propulsive efficiency at high air speeds. At low air speeds, its thrust efficiency falls off and its fuel consumption becomes excessive. The Rolls-Royce Conway By-pass is designed to improve the efficiency of the jet engine at low air speeds. As will be seen by reference to Fig. 39, part of the air from the low-pressure compressor by-passes the high-pressure compressor, the combustion chambers and the turbine. This relatively low speed air is mixed with the high speed hot gases from the combustion chambers in the tail pipe—thus reducing the overall velocity of the jet stream.

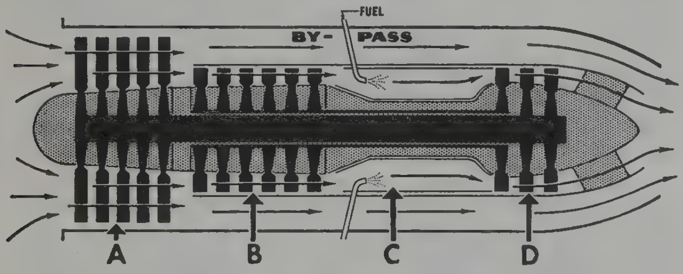


Fig. 26. Conway By-Pass Engine.

A. Primary Compressor. B. Secondary Compressor (smaller in diameter to permit the By-Pass). C. Flame Tubes and Burner Manifolds. D. Turbine.

THE AFTERBURNER

In a turbojet engine, the ratio of air to fuel is roughly 85 to 1. About a fourth of this air is used to burn the fuel, whose heat expands the air, causing it to rush out the tail pipe at tremendous speed. The **Afterburner** is a device designed to use this excess air to burn more fuel, and create a burst of additional power — a sort of violent "kick in the pants". Fundamentally, the Afterburner is a ram jet engine attached to the exhaust of a turbojet engine. The "ram" effect is supplied by the turbojet discharge — regardless of whether the airplane is moving at high speed or standing on the ground. It would be more efficient to burn the additional fuel in the high pressure air ahead of the turbines, but there are no materials available for the highly stressed turbine blades which would tolerate such temperatures. Afterburning is the next best thing.

The Afterburner is a length of tube added to the engine's exhaust tail pipe, through which the stream of jet air is escaping. Fig. 40 shows the type of burner assembly used in the Allison Engine Afterburner to inject fuel into the air stream and ignite it. It resembles, somewhat, the burner on the gas stove and is designed to provide turbulence and keep the fuel-air mixture from being blown out the tail pipe before it can burn.

The "eyelid" or "clamshell" assembly at the exhaust end is controlled by nozzles that open and close automatically. Its purpose is to enlarge the outlet opening to prevent overheating when the afterburner is turned on.

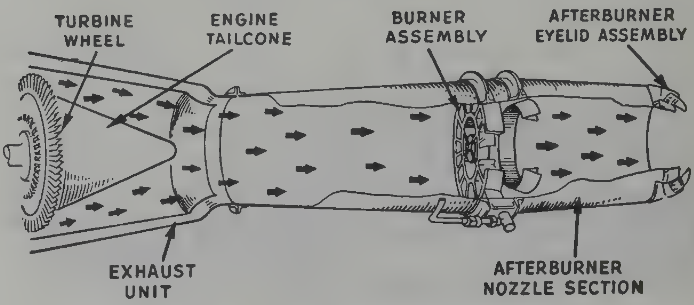


Fig. 40. Allison Engine Afterburner.

The Afterburner provides bursts of increased thrust of as much as 50. This added power is available for take-off, climb, or emergency combat use. Why do we not use this increased power continuously? Excessive fuel consumption—roughly 1 lb. of fuel per lb. of thrust. In Britain "afterburning" is referred to as "reheating".

THE TURBOFAN ENGINE

The **Turbofan Engine** (Fig. 41) is a turbojet with a "fan" added at the front end ahead of the compressor. The diameter of the fan is greater than that of the engine proper, so that some of the air through the blades is accelerated backward on the outside of the engine, providing extra thrust. This extra thrust is available for increased take-off, climb and cruise performance, reduced fuel consumption and hence better payload/range. In some Turbofan type engines, the fan is mounted aft of the turbine blades instead of ahead of the compressor, and is driven by the turbine wheel which forms part of the fan assembly.

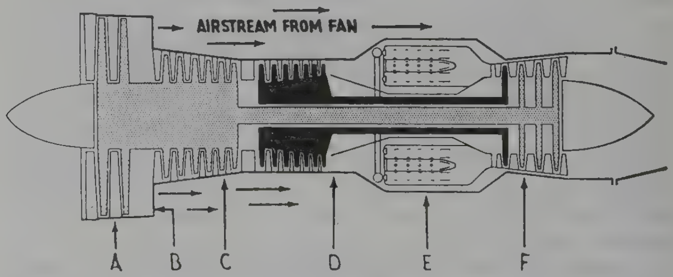


Fig. 41. Pratt & Whitney Turbofan Engine.

A—Fan. B—Duct through which airstream from fan is displaced backwards. C—Low pressure Compressor. D—High pressure Compressor. E—Flame Tubes. F—Turbine driving compressors and fan.

Meteorology . . .

> *"Man lives at the base of an invisible ocean of air termed the atmosphere." — Pick.*

This atmosphere is forever in a state of commotion and physical change, giving rise to weather conditions which vary throughout the range of an extremely vast scale. The airman not only **lives** at the base of this sea of air, but navigates **through** it. The weather, therefore, is a matter of vital concern to him — particularly conditions such as fog, ice formation, thunderstorms, and line squalls, which present unusual hazards to flying.

To minimize the hazards to air navigation being constantly manufactured in the "weather factory", a vast world-wide meterological organization has been built up, to collect, analyze and broadcast information relative to the ever changing phenomena of the upper air.

The pilot can today avail himself of last minute weather reports and forecasts along all the regularly established air routes. In addition, he can secure much valuable weather data with reference to areas located off the organized airways. He must, however, possess sufficient "weather sense" to be able to size up and deal with sudden changing conditions which may be encountered at any stage along his route. The few brief notes which follow are intended to cover the highlights of the subject only. The student of aviation will be well advised, however, to include meteorology among the subjects marked for further detailed study from some of the excellent manuals which are available on the subject.

Beyond the atmosphere lies Space, and the most challenging adventure man has ever set his mind to embark upon. Some of you who read these lines will be destined to play an active role in the Conquest of Space. But the approach to that mysterious realm of the stars lies through the atmosphere, beyond which a great many of us living today may never venture — but whose navigation will be the primary concern of this Chapter on Meteorology.

THE ATMOSPHERE

Air, which is the material of which the atmosphere is composed, is a mixture of invisible gases. At altitudes up to 50 miles, the atmosphere consists of approximately 78% Nitrogen and 21% Oxygen. The remainder is made up of Argon, Carbon Dioxide, several other gases, and water vapour. Water vapour acts as an independent gas mixed with air.

Water vapour is found only in the lower levels of the atmosphere. From the standpoint of weather, however, it is the most important component of the air. Because it can change into water droplets or ice crystals under atmospheric conditions of temperature and pressure, water vapour is responsible for the formation of clouds and fog. However, just when and under what conditions water vapour will change to a visible form is difficult to predict and is made more difficult by the fact that the amount of water vapour in the air is never constant, but varies from day to day and even from hour to hour.

The lower layer of the atmosphere contains an enormous number of microscopic impurities such as salt, dust and smoke particles. They are important to aviation for they are often present in sufficient quantities to reduce visibility. They also have a function in the condensation process.

The upper layers of the atmosphere do not contain dust particles or impurities for the Sun's light to reflect off, and for this reason appear deep cobalt blue to black in colour.

The atmosphere has weight. Although the weight of the atmosphere is only about one millionth the weight of the earth, it does exert a force or pressure on the surface of the earth. A square inch column of air weighs approximately 14.7 lbs. at sea level. This weight diminishes with height. At 20,000 feet, a square inch column weights 6.75 lbs.

The characteristics of the atmosphere vary with time of day, season of year and latitude. Consequently only average values are referred to in this manual.

PROPERTIES OF THE ATMOSPHERE

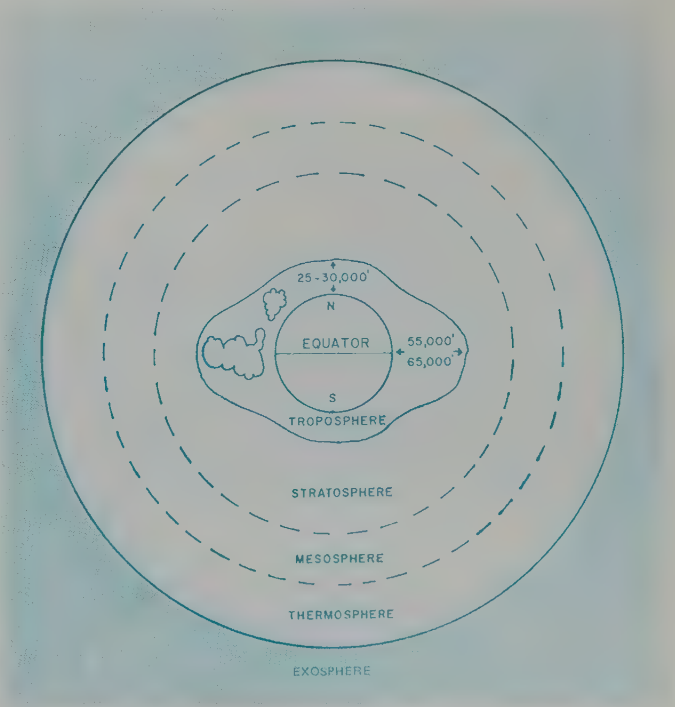
Mobility, capacity for expansion and capacity for compression are the principal properties of the atmosphere. These characteristics are of the utmost importance in a study of weather for they in combination are the cause of almost all atmospheric weather phenomena. The capacity for expansion is especially important. Air is often forced to rise by various lifting agents (thermal, frontal or mechanical means). Rising in areas of decreasing pressure, the parcel of air expands. In expanding, it cools. The cooling process may bring the temperature of the parcel of air to the degree where condensation occurs. Thus clouds form and precipitation may take place. Conversely, sinking air, as the external pressure increases, decreases in volume with an attendant rise in temperature.

DIVISIONS OF THE ATMOSPHERE

The atmosphere consists of four distinct layers surrounding the Earth for a depth of many hundreds of miles. They are, in ascending order, the Troposphere, the Stratosphere, the Mesosphere and the Thermosphere.

THE TROPOSPHERE. This is the lowest layer of the atmosphere, and varies in height in different parts of the world from roughly 28,000 feet above sea level at the Poles to 54,000 feet at the Equator. Within the Troposphere the pressure, density and temperature all decrease rapidly with height. Most of the "weather" occurs in the Troposphere, because of the presence of water vapour and strong vertical currents. In the upper regions of the Troposphere, winds are strong and the fast moving Jet Streams occur.

The top layer of the Troposphere is known as the **Tropopause.** Here the temperature ceases to drop and remains substantially constant at about -56°C. The height of the



Divisions of the Atmosphere

Tropopause varies, as already stated from the Poles to the Equator, but also from summer to winter.

THE STRATOSPHERE. For a distance of about 9 miles above the Tropopause, there is a layer known as the Stratosphere in which the pressure continues to decrease but in which the temperature remains relatively constant in the vicinity of -56°C. This layer also varies in thickness, being quite deep over the Poles and thinner over the Equator. Water vapour is almost non-existent and air currents are minimal. The top layer of the Stratosphere is called the **Stratopause.**

THE MESOSPHERE. The Mesosphere is characterized by a marked increase in temperature. At a height of about 30 miles, the temperature reaches 10°C. The rise in temperature is due to the presence of a layer of ozone which absorbs more of the sun's radiation. In the top layer of the Mesosphere, called the **Mesopause**, the temperature again drops rapidly reaching a level of about -100°C at 50 miles above the Earth.

THE THERMOSPHERE. Temperature again begins to rise in the Thermosphere and increases for an indefinite distance into Space, rising as high as 3000°C at 400 miles. This does not mean that a space ship, if it was cruising at this height, would experience a temperature of 3000°C by contact with the atmosphere. The temperature in these rarified layers is based on the "kinetic" theory of gases. The only heat the space ship would experience would be what it would receive from the radiation of the sun. The spectacular auroras form in the upper regions of the Thermosphere.

Within the Thermosphere is a region known as the **Ionosphere**, which extends from about 50 miles to 250 miles above the Earth's surface. Within this region, free electron density is very great and affects radio communication. The Ionosphere is the layer which reflects low and medium frequency waves back to the Earth. Very high frequency waves, however, penetrate this layer.

Beyond the Ionosphere lies a layer so thin that the pressure drops to little more than a vacuum. Under these conditions the concept of temperature has little meaning and is usually replaced by definitions of the energy states of individual molecules. This thin upper layer is known as the **Exosphere.**

SPACE. Since air becomes gradually thinner with increasing altitude, the upper limit of the atmosphere is, for all practical purposes, difficult to define. Now that man has invaded the cosmic realm of outer space — just where exactly does Space actually begin? At an altitude of 90 to 100 miles one is entering the realm of satellites, and aerodynamic lift is no longer a requirement for maintaining height above the Earth. This region has been accepted by some authorities as the boundary of outer Space. 90 miles up is recognized as the limit of national sovereignty.

STANDARD ATMOSPHERE

The decrease with height of pressure, density and temperature which occurs in the lower layers of the atmosphere is not constant but varies with local conditions. However, for aeronautical purposes, it is necessary to have a "standard" atmosphere. There are several different Standard Atmospheres in use, but they vary only slightly.

The **ICAO Standard Atmosphere** for the Continent of North America, based on summer and winter averages at Latitude 40° is shown in Fig. 1.

Altitude	Pressure in inches of Mercury	Temperature in degrees Celsius	Relative Density
Sea Level	29.92	+15	1
5,000 ft.	24.89	+ 5.1	0.86
10,000 ft.	20.58	— 4.8	0.74
15,000 ft.	16.88	—14.7	0.63
20,000 ft.	13.75	—24.6	0.53
30,000 ft.	8.88	—44.4	0.37
40,000 ft.	5.54	—56.5	0.24
50,000 ft.	3.44	—56.5	0.15

Fig. 1. Standard Atmosphere.

CLOUDS

To a pilot knowledgeable in the science of meteorology, clouds are an indication of what is happening in the atmosphere. The location and type of cloud are evidence of such weather phenomena as fronts, turbulence, thunderstorms, and tell the pilot what type of conditions may be expected during flight.

CLASSIFICATIONS OF CLOUDS

Clouds are classified into four families: high clouds, middle clouds, low clouds and clouds of vertical development.

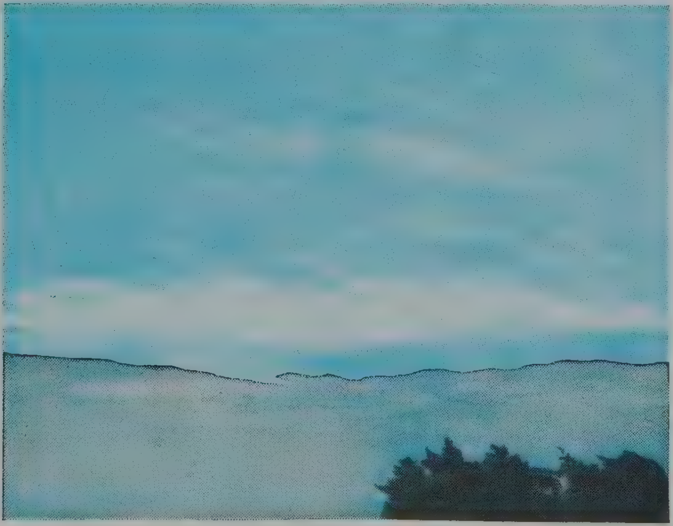


Fig. 2. Cirrus.

As well, clouds are identified by the way in which they form. There are two basic types: cumulus and stratus.

Cumulus Clouds form in rising air currents and are evidence of unstable air conditions.

Stratus Clouds form in horizontal layers and usually form as a layer of moist air is cooled below its saturation point.

Clouds from which precipitation falls are designated **nimbus clouds.**

The cloud heights referred to below are for the Temperate Regions. In the Polar Regions, clouds tend to occur at lower heights and in the Tropics at greater heights.

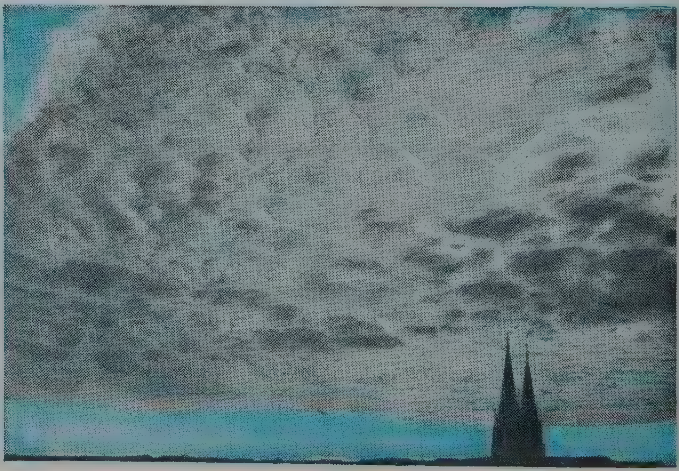


Fig. 3. Altocumulus.

HIGH CLOUDS

The bases of high clouds range from 16,500 feet to 45,000 feet and average about 25,000 feet in the Temperate Regions. They are composed of ice crystals.

Cirrus (Ci). Very high. Thin, wavy sprays of white clouds, made up of slender, delicate curling wisps or fibres. Sometimes takes the form of feathers or ribbons, or delicate fibrous bands. Often called "cats' whiskers" or "mares' tails".

Cirrocumulus (Cc) — Thin clouds, cotton or flake-like. Often called "mackerel sky". Gives little indication of future weather conditions.

Cirrostratus (Cs) — Very thin high sheet cloud through which the sun or moon is visible, producing a "halo" effect. Cirrostratus is frequently an indication of an approaching warm front or occlusion and therefore of deteriorating weather.

MIDDLE CLOUDS

The bases of middle clouds range from 6500 feet to 23,000 feet. They are composed of ice cystals or water droplets, which may be at temperatures above freezing or may be supercooled.

Altocumulus (Ac) — A layer or series of patches of rounded masses of clouds that may lie in groups or lines. Sometimes they indicate the approach of a front but usually they have little value as an indication of future weather developments. Altocumulus Castellatus (Acc) is altocumulus with a turreted appearance.

Altostratus (As) — A thick veil of grey cloud that generally covers the whole sky. At first, the sun or moon may be seen through the cloud, but they disappear as the cloud gets thicker. The presence of altostratus indicates the near approach of a warm front. The base of the cloud slopes downward towards the warm front. Some light rain or snow may fall from thick altostratus. Icing may occur in this cloud.

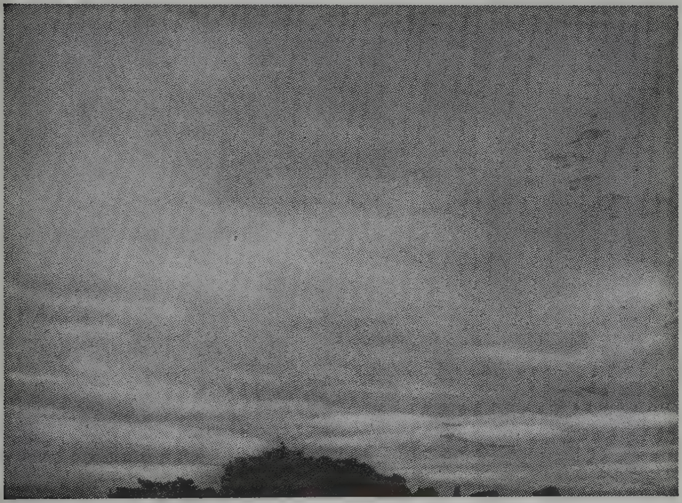


Fig. 4. Stratocumulus.

LOW CLOUDS

The bases of low clouds range from surface height to about 6500 feet. They are composed of water droplets which may be supercooled and sometimes of ice crystals.

Stratus (St) — A uniform layer of cloud resembling fog but not resting on the ground. Drizzle often falls from stratus. When stratus cloud is broken up by wind, it is called Fractostratus.

Stratocumulus (Sc) — A layer or series of patches of rounded masses or rolls of cloud. It is very often thin with blue sky showing through the breaks. It is common in high pressure areas in winter and gives a little light precipitation sometimes.

Nimbostratus (Ns) — A low layer of uniform, dark grey cloud. When it gives precipitation, it is in the form of continuous rain or snow. The cloud may be more than 15,000 feet thick. It is generally associated with warm fronts.

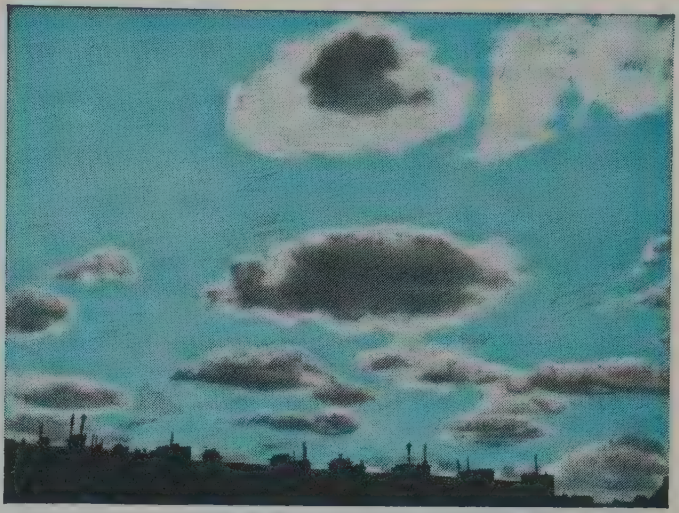


Fig. 5. Cumulus.

CLOUDS OF VERTICAL DEVELOPMENT

The bases of this type of cloud may form as low as 1500 feet. They are composed of water droplets when the temperature is above freezing and of ice crystals and supercooled water droplets when the temperature is below freezing.

Cumulus (Cu) — Dense clouds of vertical development. They are thick, rounded and lumpy and resemble cotton balls. They usually have flat bases and the tops are rounded. They cast dense shadows and appear in great abundance during the warm part of the day and dissipate at night. When these clouds are composed of ragged fragments, they are called Fractocumulus (Fc).

Heavy Cumulus (Cu +) — Cumulus clouds that build up into high towering masses. They are likely to develop into cumulonimbus. Rough air will be encountered underneath the cloud. Heavy icing may occur in this cloud type.

Cumulonimbus (Cb) — Heavy masses of cumulus clouds that extend well above the freezing level. The summits often spread out to form an anvil shaped top that is characteristic of thunderstorm and showery conditions. Violent vertical currents exist within the cloud. Hail is frequently present within the cloud and may occasionally fall from it. A line of cumulonimbus is often an indication of a cold front. The cloud should be avoided

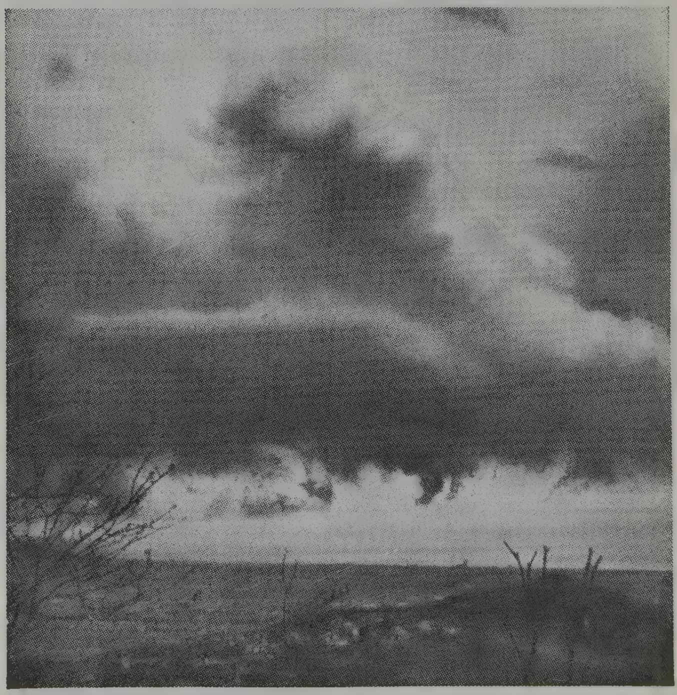


Fig. 6. Cumulonimbus.

on account of its turbulence, the danger of heavy icing and violent electrical activity. Cumulonimbus clouds may be embedded in stratiform clouds.

SKY CONDITION

There are five general types of sky:

1. Clear: Less than 1/10th of the sky is covered by clouds.

2. Scattered: 1/10th to 5/10ths of the sky is covered by clouds.

3. Broken: More than 5/10ths but not more than 9/10ths of the sky is covered.

4. Overcast: More than 9/10ths of the sky is covered.

5. Obscured: More than 5/10ths of the sky is hidden by an "obscuring medium", such as rain, snow, hail, fog, haze, dust, smoke, etc.

PRESSURE

Atmospheric pressure is important to the pilot for two reasons. Firstly, airplane altimeters are operated by atmospheric pressure and must be properly set to give correct readings of altitude. Secondly, pressure distribution in the atmosphere controls the winds which are of great importance to the pilot in planning cross country flights.

ATMOSPHERIC PRESSURE

The pressure of the atmosphere at any point is due to the weight of overlying air. Pressure at the surface of the Earth is usually measured by the **Mercury Barometer** and is expressed in inches of mercury (written "Hg). A measurement so expressed really means the length of a column of mercury, the weight of which will balance a column of air extending from the ground to the top of the atmosphere (Fig. 7).

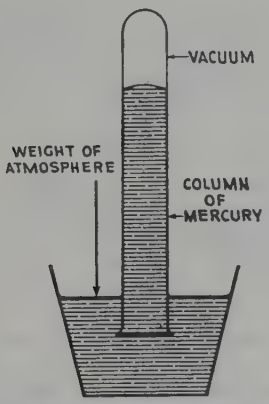


Fig. 7. Principle of the Mercury Barometer.

Pressure, however, is a force and in meteorological work it is common to employ a unit, the **Millibar**, to measure it. A Millibar is a pressure exerted on an area of 1 square centimeter by a force of 1000 Dynes.

A pressure expressed as 29.92 inches of mercury is equivalent to 1013.2 millibars.

STATION PRESSURE, SEA LEVEL PRESSURE AND ALTIMETER SETTING

At any observing station at which an atmospheric pressure reading is taken, the reading will show the actual weight of a column of air at the elevation of that station. This reading is called **station pressure.** Since the weight of the atmosphere decreases with altitude, it follows that the atmospheric pressure reading at a station at 5000 feet elevation will be less than that at a station at 1000 feet and still less than that at a station at sea level.

To have a consistent record of the distribution of atmospheric pressure, each observing station translates its reading into terms of sea-level pressure. This standard is called **Mean Sea Level (MSL).** In determining MSL, local temperature, as well as difference in elevation is taken into account. Sea level pressure is reported in millibars.

To make the altimeter of an airplane effective, it must be set to a standard atmospheric pressure. This pressure reading is called the **altimeter setting** and differs slightly from sea level pressure in that standard sea level temperature of 15°C is used in computing the equivalents. When correctly set, the altimeter will then read the true elevation of the airport at which the airplane is parked. (Conversely, if a pilot does not know the altimeter setting but does know the elevation of the airport at which he is parked, he can dial in the correct elevation and get also the correct altimeter setting.) Altimeter setting is reported in inches of mercury.

PRESSURE SYSTEMS

The pressure readings that are taken at various weather reporting stations all over North America are transmitted to forecast offices and are plotted on specially prepared maps. Areas of like pressure are joined by lines, wind direction arrows are entered and the result is a **Weather Map** that gives the weather man a symbolic picture of the weather over the whole continent.

The lines that join, on a weather map, areas of equal barometric pressure are called **isobars.** These lines are drawn on the map at four millibar intervals, above and below the value of 1000 millibars. When the isobars are drawn in, they form definite patterns. They never cross, but form roughly concentric circles and form themselves into distinct areas of high and low pressure.

The various types of pressure systems are: lows, secondary lows, troughs, highs, ridges and cols. They are illustrated in Fig. 8 as they would appear on a typical weather map.

The pressure patterns on the weather map are very like contour lines on a topographical map, the high pressure areas correspond to hills and the low pressure areas to valleys.

These pressure systems are constantly moving or changing in appearance. Lows may deepen or fill and highs may build or weaken. Most systems move in a general west to east direction.

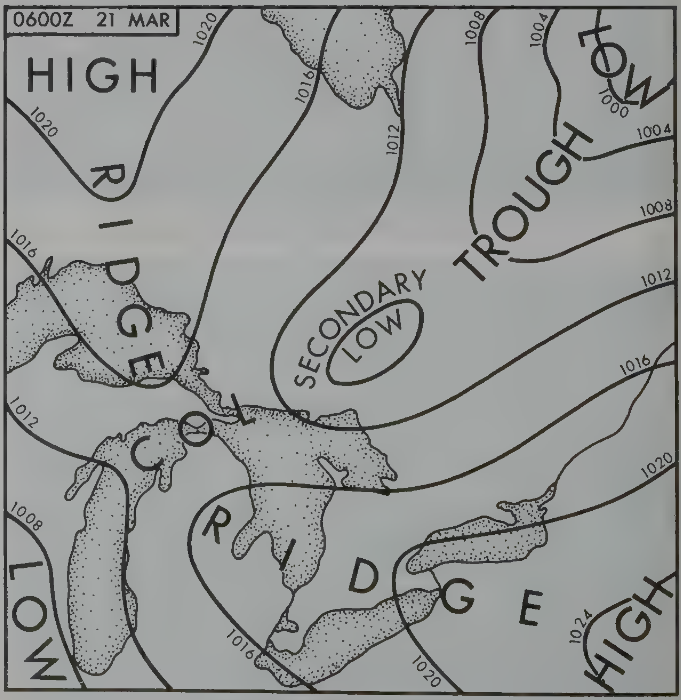


Fig. 8. Pressure Systems.

If we put down on a map beside the barometer readings and wind arrows the state of the weather, we shall see that in the high pressure areas it is usually fine and clear, probably cooler, while in the low pressure areas, it is generally rainy and cloudy on the east side, and probably fine on the west side. The weather, in fact, is intimately connected with the shape of the isobars.

LOW PRESSURE AREAS

Areas of low pressure are called Cyclones, Depressions or simply Lows. A low is a region of relatively low pressure with the lowest pressure at the centre.

A low may cover a small region such as a county, or it may extend across half a continent. Some are much deeper than others. A tornado, for example, is a very deep, small but concentrated low. A deep low is one where the barometer is very low in the centre and the isobars are rather close together. A shallow depression is low in the centre, but not much lower than the surrounding areas.

Depressions seldom stay long in one place but generally move in an easterly direction. Their average rate of movement is 500 miles a day in summer, and 700 miles a day in winter. Their drift is generally to north-east or south-east. Only rarely is there an exception to this pattern of easterly drift of low pressure areas.

SECONDARY LOW

This is a smaller disturbance of a cyclonic nature which forms within the area dominated by the main depression. The secondary centre revolves around the main centre in an anticlockwise direction. Secondaries are frequently associated with thunderstorms in summer and gales or heavy precipitation in winter.

TROUGH OF LOW PRESSURE

This is an elongated 'U'-shaped area of low pressure with higher pressure on either side, which may bring about a gradual windshift.

The term "trough" is also applied to the 'V'-shape formed by the sharp bending or kinking of the isobars along a frontal surface, sometimes referred to as a V-shaped Depression. (see **"Fronts"**). Sudden windshifts may be expected, accompanied by the type of weather generally associated with fronts.

COL

A col is a neutral region between two highs and two lows. Weather conditions are apt to be unsettled. In winter, the mixture of dissimilar air frequently produces fog. In summer, showers or thunderstorms may occur. While it is quite possible for weather conditions to be fair, generally speaking, cols may be regarded as regions of undependable weather.

HIGH PRESSURE AREAS

A High or Anti-cyclone, is an area of relatively high pressure, higher than the surrounding regions, with the highest pressure in the centre and decreasing towards the outside. The accompanying weather is usually fine to fair, clear and bright, with light, moderately cool breezes, becoming cooler at night with possibly a little frost. In winter a high very often brings clear, cold weather.

Occasionally, however, an Anticyclone occurs in which a persistent cloud sheet develops, causing dull, gloomy weather.

The winds associated with high pressure are usually light and rather variable. They circulate in a clockwise direction around the centre, blowing outwards into the lows.

Highs move much more slowly across the country than depressions and occasionally remain almost stationary for days at a time.

RIDGE OF HIGH PRESSURE

An anti-cyclone Ridge is a neck or ridge of high pressure with lower pressure lying on either side. The weather in a ridge is generally fine to fair.

PRESSURE CHANGES

Pressure readings are taken at regular intervals (usually hourly) at weather stations. Weather maps are prepared eight times a day at three hour intervals. From these readings and maps, the changes in pressure can be observed and approaching weather forecast. If a low, for example, is approaching a station, the pressure will steadily fall. Once the centre of the low has passed by, the pressure will begin to rise. This pattern of changing pressure is called **pressure tendency.**

PRESSURE GRADIENT

If some of the air were removed from a room, the pressure would be reduced and the pressure outside would force air in through the doors and windows until the room was again filled with the normal amount of air. Similarly, in the case of low and high pressure areas, there is a tendency for the higher pressure air in a high to flow towards the area of lower pressure.

The speed at which this movement of air occurs depends on the **pressure gradient.** The pressure gradient is defined as the rate of change of pressure over a given distance measured at right angles to the isobars.

The steepness of the pressure gradient is measured by the nearness of the isobars. Where the isobars are spaced widely apart, the pressure gradient is shallow and the movement of air (wind) is slow or light. Where the isobars are very close together, the gradient is steep and the wind is strong.

CORIOLIS FORCE

The air moving from a high pressure area to a low pressure area does not, however, flow directly from the one to the other. It is deflected to the right in the Northern Hemisphere by a force called the **Coriolis Force** and as a result flows parallel to the isobars.

Anything moving above the surface of the Earth will continue to move in a straight line if no force acts on it, but the Earth in its rotation moves under the moving body. The moving body is, therefore, apparently deflected to the right in the Northern Hemisphere. This is known as **Fennell's Law**. The apparent deflecting force is called **Coriolis Force.** (Fig. 8.1.)

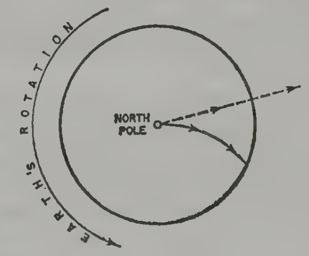


Fig. 8.1. Coriolis Force.

Cut out a paper disk to represent the Earth. Place a pin through the centre to represent the North Pole. Rotating the disk around the pin (anticlockwise) to represent the Earth's rotation, attempt to draw a straight line (the dotted line in the figure) to represent a wind blowing from North to South. The line will curve as shown, or in other words, be deflected to the right.

Hence, the wind does not blow straight into an area of low pressure from all sides but is deflected to the right and blows around the area of low pressure **anti- clockwise** in the Northern Hemisphere.

It is the same force which causes water to swirl **anti-clockwise** in a wash basin when the plug has been removed.

In the case of a high pressure area, the air flows out from the high pressure, but is deflected to the right as in the former case. As a result, the wind blows clockwise round an area of high pressure in the Northern Hemisphere.

In either case, if you stand with your back to the wind, the low pressure area will be on your left side. This is known as **Buy Ballot's Law.** In the Southern Hemisphere, the reverse is the case.

SURFACE FRICTION

In the lower levels of the atmosphere, a third force acts on the direction and speed of the air moving from areas of high pressure to areas of low pressure. This force is **Surface Friction.** Friction between the air masses and the surface of the earth tends to slow down the movement of the air, thereby reducing the wind speed. This in turn retards the Coriolis Effect. As a result, air tends to move across the isobars at a slight angle inwards towards the centre of the lows and outwards from the centres of the highs.

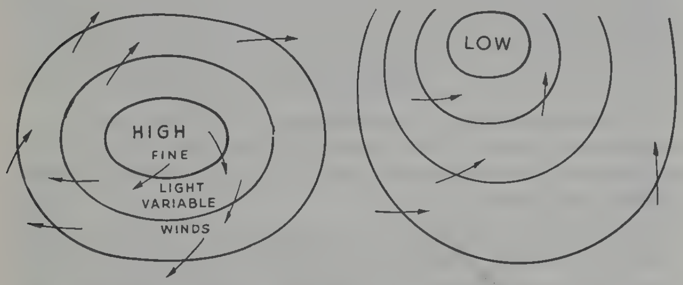


Fig. 9. Surface Friction Effect on Air Movement Across Isobars.

The more surface friction, the greater the angle at which the flow of air is deflected from a flow parallel to the isobars. Over water, it is less than over land where the roughness of the terrain may cause a deflection of as much as 40°. Over water, the deflection is rarely more than 10°. The friction effect is greatest near the surface of the earth, but may be carried aloft by turbulence to heights as great as 2000 feet. Above this altitude, it is practically negligible and the winds tend to flow parallel to the isobars as a result of the Coriolis Force.

CENTRIFUGAL FORCE

Centrifugal Force, acting on the circulating flow of air around the high and low pressure areas, tends to *increase* wind speed in the high pressure areas and *decrease* it in the low pressure areas.

CONVERGENCE AND DIVERGENCE

Convergence. The inflow of air **into** an area is called Convergence. It is usually accompanied by an upward movement of air to permit the excess accumulation of air to escape. Areas of convergent winds are favorable to the occurrence of precipitation in the form of thunderstorms, rain, hail or snow.

Divergence. When there is a flow of air **outwards** from a region, the condition is known as Divergence. The outflow is compensated by a downward movement of air from aloft. Areas of divergent winds are not favorable to the occurrence of precipitation.

WINDS

The horizontal movement of air, called **wind,** is a factor of great importance to a pilot as he plans a flight. Upper winds encountered enroute will affect groundspeed either favourably or detrimentally and thus have a bearing on time enroute and fuel consumption. Surface winds are important in landing and takeoff.

THE HEMISPHERIC PREVAILING WINDS

Since the atmosphere is fixed to the Earth by gravity and rotates with the Earth, there would be no circulation if some force did not upset the atmosphere's equilibrium. The heating of the Earth's surface by the sun is the force responsible for creating the circulation that does exist.

Because of the curvature of the Earth, the most direct rays of the sun strike the Earth in the vicinity of the Equator resulting in the greatest concentration of heat, the largest possible amount of reradiation and the maximum heating of the atmosphere in this area of the Earth. At the same time, the sun's rays strike the Earth at the Poles at a very oblique angle, resulting in a much lower concentration of heat and much less reradiation so that there is, in fact, very little heating of the atmosphere over the Poles and consequently very cold temperatures.

Cold air, being more dense, sinks and hot air, being less dense, rises. Consequently, the rising warm air at the Equator becomes even less dense as it rises and its pressure decreases. An area of low pressure, therefore, exists over the Equator.

Warm air rises until it reaches a certain height at which it starts to spill over into surrounding areas. At the Poles, the cold dense air is sinking. Air from the upper levels of the atmosphere flows in on top of it increasing the weight and creating an area of high pressure at the Poles.

The air that rises at the Equator does not flow directly to the Poles. Due to the rotation of the Earth, there is a build up of air at about 30° North Latitude. (The same phenomenon occurs in the Southern Hemisphere.) Some of the air sinks, causing a belt of high pressure at this latitude.

The sinking air reaches the surface and flows north and south. The air that flows south completes one cell of the Earth's circulation pattern, as shown in Fig. 10. The air that flows north becomes part of another cell of circulation between 30° and 60° North Latitude. At the same time, the sinking air at the North Pole flows south and collides with the air moving north from the 30° high pressure area. The colliding air is forced upward and an area of low pressure is created near 60° North. The third cell circulation pattern is created between the North Pole and 60° North.

Because of the rotation of the Earth and the Coriolis Force, air is deflected to the right in the Northern Hemisphere. As a result, the movement of air in the polar cell circulation produces the **polar easterlies.** In the circulation cell that exists between 60° and 30° North, the movement of air produces the **prevailing westerlies.** In the tropic circulation cell, the **northeast trade winds** are produced. These are the so-called permanent wind systems of the Earth. They are illustrated in Fig. 10.

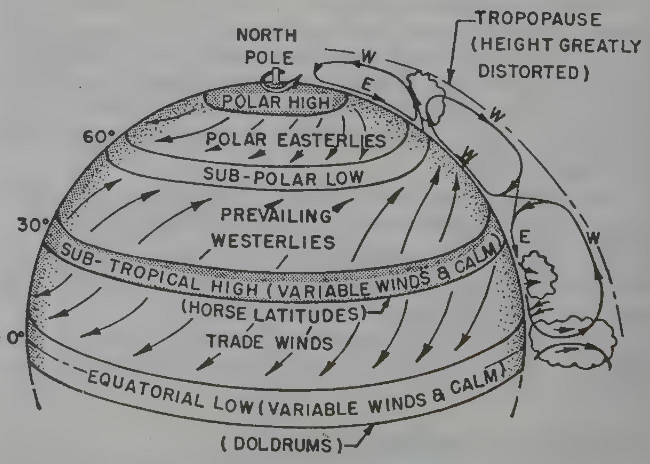


Fig. 10. Wind Circulation.

LOCAL WINDS

The movement of air around high and low pressure areas has been discussed above.

Surface winds, however, do not always show the speed and direction that would be expected from the weather maps isobars. These variations are usually due to geographic features such as mountains and large bodies of water.

LAND AND SEA BREEZES

Land and Sea Breezes are caused by the differences in temperature over land and water. The Sea Breeze occurs during the day when the land area heats more rapidly than the water surface. This results in the pressure over the land being lower than that over the water. The pressure gradient is often strong enough for a wind to blow from the water to the land.

The Land Breeze blows at night when the land becomes cooler. Then the wind blows towards the warm, low pressure area over the water.

Land and sea breezes are very local and affect only a narrow area along the coast.

MOUNTAIN WINDS

Katabatic Winds, sometimes called Mountain Breezes, blow down mountain slopes towards the warmer valleys.

Mountain ranges sometimes act as a barrier which holds back the air and deflects it so that it flows parallel to the range. If there is a pass in a mountain range, the wind will rush through this pass as through a funnel with considerable speed.

Valley Breezes are winds that blow up the valleys. They are known as **Anabatic Winds.**

The **Mountain Wave** is the most treacherous of the local wind systems associated with mountains.

The Mountain Wave

The flow of air over a mountain will set up a wave pattern known as a Mountain Wave. Fig.11 illustrates the type of wave pattern which may be activated by a very strong wind. Note the up and down drafts (the speeds of which may exceed 5000 ft/min.) and the rotating eddies formed downstream. The mountain wave will sometimes occur in clear air. However, if moisture is present the following cloud types may develop: (i) Cap Cloud, which lies along the top of the ridge. (ii) Lens-shaped (lenticular) Cloud, lying in bands above the crests of the waves. (iii) Rotor Clouds, which form in the rolling eddies downstream. Cloud, when present, provides visible warning of the presence of the wave.

ACSL

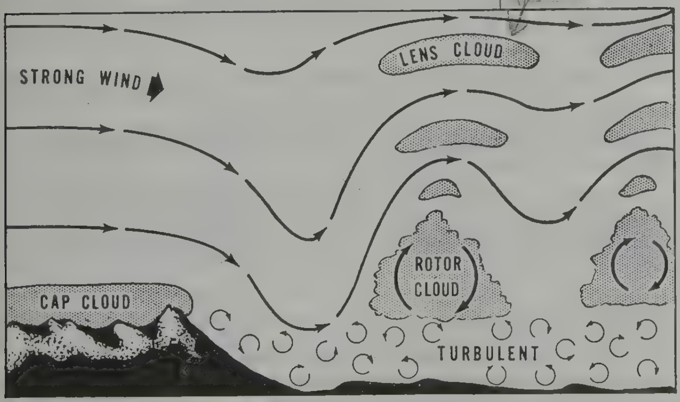


Fig. 11. The Mountain Wave.

When flying over a mountain ridge where wave conditions exist: (i) Avoid ragged and irregular shaped clouds—the irregular shape indicates turbulence. (ii) Approach the mountain at a 45-degree angle. If you should suddenly decide to turn back, a quick turn can be made away from the high ground. (iii) Avoid flying in cloud on the mountain crest (cap cloud) because of strong downdrafts and turbulence. (iv) **Always remember that your altimeter can read over 3000 ft. in error on the high side in mountain wave conditions.**

GUSTINESS

A **Gust** is a rapid and irregular fluctuation of varying intensity in the upward and downward movement of air currents. It may be associated with a rapid change in wind direction. Gusts are caused by mechanical turbulence that results from friction between the air and the ground and by the unequal heating of the earth's surface, particularly on hot summer afternoons.

SQUALLS

A Squall is a sudden increase in the strength of the wind of longer duration than a gust and may be caused by the passage of a fast moving cold front or thunderstorm. Like a gust, it may be accompanied by a rapid change of wind direction.

DIURNAL VARIATIONS

Diurnal (Daily) Variation of Wind is caused by strong surface heating during the day which causes turbulence in the lower levels. This turbulence brings down air from higher levels which is moving faster and increases the surface wind. At night there is less turbulence and the surface winds become lighter.

DUST DEVILS

Dust devils are phenomena that occur quite frequently on the hot dry plains of mid-western North America. They can be of sufficient force to present a hazard to pilots of light airplanes flying at low speeds.

They are small heat lows that form on clear hot days. Given a steep lapse rate caused by cool air aloft over a hot surface, little horizontal air movement, few or no clouds, and the noonday sun heating flat arid soil surfaces to high temperatures, the air in contact with the ground becomes superheated and highly unstable. This surface layer of air builds until something triggers an upward movement. Once started, the hot air rises in a column and draws more hot air into the base of the column. Circulation begins around this heat low and increases in velocity until a small vigorous whirlwind is created. Dust devils are usually of short duration and are so named because they are made visible by the dust, sand and debris that they pick up from the ground.

Dust devils pose the greatest hazard near the ground where they are most violent. Pilots proposing to land on superheated runways in areas of the mid-west where this phenomenon is common should scan the airport for dust swirls or grass spirals that would indicate the existence of this hazard.

WIND DIRECTION

In a discussion of wind direction, the compass point from which the wind is blowing is considered to be its direction. Therefore, a north wind is one that is blowing from the north towards the south.

VEERING AND BACKING

The wind **veers** when it changes direction clockwise. Example: The surface wind is blowing from 270°T. At 2000 feet it is blowing from 280°T. It has changed in a right-hand, or clockwise direction.

The wind **backs** when it changes direction anti-clockwise. Example: Wind direction at 2000 feet, 90°T. Wind at 3000 feet, 85°T. It is changing in a left-hand, or anti-clockwise direction.

In a descent from several thousand feet above the ground to ground level, the wind will usually be found to back and also decrease in velocity, as the effect of surface friction becomes apparent. In a climb from the surface to several thousand feet AGL, the wind will veer and increase.

At night, surface friction decreases as surface cooling reduces the eddy motion of the air. Surface winds will back and decrease. During the day, as surface friction intensifies, the surface winds will veer and increase.

WIND SHEAR

Wind shear is the sudden "tearing" or "shearing" effect encountered along the edge of a zone in which there is a violent change in wind speed or direction. It can exist in a horizontal or vertical direction and produces churning motions and consequently turbulence.

Wind shear will often be encountered when climbing or descending through a temperature inversion. It can also be expected in a frontal surface. It is a phenomenon associated with the Jet Stream. (See below.)

A very severe form of wind shear is sometimes associated with strong temperature inversions near the ground. In this case, it can pose a serious hazard to airplanes during take-off or landing. An aircraft passing through the transition zone and encountering the wind shear phenomenon may experience a large loss of airspeed. A few hundred feet off the ground, this could be a dangerous situation. The intensity of the turbulence varies with the speed of the warm air aloft. The cold air near the ground is usually quite calm.

THE JET STREAM

Narrow bands of exceedingly high speed winds are known to exist in the higher levels of the atmosphere at altitudes ranging from 20,000 to 30,000 ft. or more. They are known as Jet Streams. They are usually about 300 miles wide and will encircle an entire hemisphere in a snake-like pattern. As many as three major Jet Streams may traverse the North American Continent at any given time, their locations roughly: one lying across Northern Canada, one across the U.S., and one extending across the Sub Tropical Latitudes. They shift location rapidly from day to day and with the seasons, consequently their position can best be found by reference to specially constructed charts prepared by the weathermen. Windspeeds in the Jet Stream vary from 100 to 250 mph and may exceed 300 mph. Knowing the location of the Jet Streams is important to the pilot who is planning long range flights at high altitudes.

Clear Air Turbulence. Closely associated with the Jet Stream when flying at high altitude is Clear Air Turbulence (CAT). This occurs in clear air with no cloud form to give warning of its existence, and can be quite violent. It is caused by wind shear.

Another form of Clear Air Turbulence which may be encountered at lower levels is Wing Tip Vortex, which is discussed in Chapter **Airmanship.**

HUMIDITY, TEMPERATURE AND STABILITY

HUMIDITY

Of all the elements which compose the lower atmosphere water vapour is the most variable. Although it forms but a small proportion of the total mass of air at any time, its effects from a flying point of view are of great importance. It is the only gas which can change into a liquid or a solid under ordinary atmospheric conditions and it is because of this characteristic that most of the weather develops.

Moisture exists in the atmosphere in two forms. In its invisible form, it is water vapour. In its visible form, it is either water droplets or ice crystals.

By a process called **Condensation,** water vapour changes into water droplets. By a process called **Sublimation,** water vapour changes into ice crystals. In its visible form, as either water droplets or ice crystals, moisture forms clouds and fog. Further developments within a cloud may lead to precipitation.

The amount of water vapour that a given volume of air can contain is governed by its temperature. Warm air can hold more moisture than cold air. When a mass of air contains the maximum amount of water vapour it can hold **at a given temperature,** it is said to be **saturated.** If the temperature falls any lower after the air is saturated, some of the invisible water vapour will condense out in the form of visible water droplets. By this process of condensation, clouds, fog and dew are formed.

If the temperature is below freezing when the condensation occurs, the water vapour changes directly into ice crystals without passing through the visible water droplet stage. This process is known as sublimation.

The process is reversible. If the visible water droplets or ice crystals are heated, they will turn back into the invisible gas, water vapour. Therefore, if fog or clouds are heated, they will disappear.

The process of condensation or sublimation cannot take place unless there are microscopic particles present in the air on which the water vapour can condense. The atmosphere contains a vast quantity of impurities, such as fine dust from deserts, smoke from industrial regions, salts from the oceans and seeds, pollen etc. Since these originate from the Earth they exist only in the lower layers of the atmosphere. They act as **Condensation Nuclei** on which the condensation of water vapour takes place when air is cooled below its saturation temperature (dewpoint).

DEWPOINT

The temperature to which unsaturated air must be cooled at **constant temperature** to become saturated (without the addition or removal of any water vapour) is called the **Dewpoint.**

When the spread between the temperature and dewpoint is very small, the air can be said to be nearly saturated and a slight drop in temperature may cause condensation in the form of clouds, fog, or precipitation.

RELATIVE HUMIDITY

The Relative Humidity is the ratio of the actual water vapour present in the air to the amount which the same volume of air would hold if it were saturated (at the same atmospheric pressure and temperature). Saturated air has 100% Relative Humidity. Completely dry air has 0% Relative Humidity.

When a given mass of air is heated and no new water vapour is added, the Relative Humidity of air **decreases.** If the mass of air is cooled, the Relative Humidity **increases.** If cooling continues long enough, the Relative Humidity will reach 100% and the air will be **saturated.**

Hence, the **smaller** the spread between temperature and dewpoint, the **higher** will be the Relative Humidity.

Fog or low clouds are likely to form when the temperature is within 2°C. of the dewpoint.

Absolute Humidity expresses the **weight** of water vapour per unit volume of air. It is usually stated in grains of water vapour per cubic foot of air. (A grain is 1/7000th part of a lb.)

TEMPERATURE

The source of energy which warms the Earth's surface, evaporates moisture into the atmosphere, and causes the movement of air which we call wind, is the **Sun.** The lower atmosphere absorbs very little of the heat radiated by the Sun. Most of the Sun's heat is absorbed by the Earth and about half of it is reflected back into the atmosphere by **Radiation.** This is important, for it means that the lower layers of the atmosphere **are heated from below and not from above.**

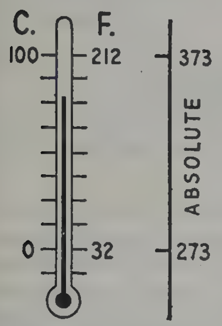
Land surfaces absorb more heat from the Sun than water surfaces, and radiate it more readily. Therefore land surfaces warm up more during the day and cool more rapidly at night than water. For the same reason, the land is warmer than the sea in summer and cooler in winter.

ISOTHERMS

On meteorological maps, lines joining places of equal temperature are known as **Isotherms**.

TEMPERATURE SCALES

The scales commonly used in meteorology to measure the temperature are the Celsius, Fahrenheit, and Absolute Scales. The Celsius Scale is used in Canada for all meteorological temperature readings.



Temperature Scales.

The CELSIUS (or CENTIGRADE) SCALE has a freezing point of 0° and a boiling point of 100°.

The FAHRENHEIT SCALE has a freezing point of 32° and a boiling point of 212°.

The ABSOLUTE SCALE assumes an absolute zero of —273°C. The Absolute Temperature can be found by adding 273 to the Celsius Temperature, e.g. + 10°C = 283° Absolute. —10°C = 263° Absolute.

To convert Celsius to Fahrenheit, or Fahrenheit to Celsius, use the following formula:

Degrees F. = 9/5 C. + 32
Degrees C. = 5/9 (F. —32)

For example: 20°F equals 5/9 (20—32) equals —6.7°C.
20°C equals (9/5 X 20) + 32 equals 68°F.

Nine degrees on the Fahrenheit Scale equal five degrees on the Celsius Scale. Do not, however, interpret this to mean that 9°F equals 5°C (9°F equals —12.8°C)

DENSITY AND TEMPERATURE

The **density** of air means its **mass** per unit of volume. Cold air is **dense** because the molecules which compose it are moving relatively slowly and are packed closely together. Warm air is **less dense** because the molecules which compose it are moving rapidly about. Hence, they take up more space, and consequently there are fewer molecules in a given volume. Since cold air is denser it is therefore **heavier** and tends to sink due to the force of gravity. Warm air, being lighter, is pushed up by the denser cold air an tends to rise.

LAPSE RATE

Since the atmosphere is heated from below, the temperature usually decreases with height through the Troposphere. The rate of decrease with height is called the **Lapse Rate.**

The NORMAL LAPSE RATE is the rate at which the average temperature of the lower atmosphere decreases with height. It may be considered as being 1.6°C per 1000 feet. Therefore, if the surface temperature is 26°C, the temperature at 10,000 feet is likely to be about 10°C.

The Lapse Rate of I.C.A.O. Standard Air is 1.98°C per 1000 feet. It is this figure which is universally used in the calibration of altimeters.

ADIABATIC LAPSE RATES. The most important cooling process in the atmosphere is cooling resulting from expansion as air is forced to rise. In a rising current of air, the temperature decreases at a rate that is entirely independent of the lapse rate in the surrounding non-rising air. Such a temperature change is said to be "adiabatic", the word "adiabatic" meaning that the temperature change takes place without adding or taking away heat from outside the parcel of air. Saturated air cools by expansion at a different rate than does unsaturated air. The **Dry Adiabatic Lapse Rate** is considered to be 3°C per 1000 feet.

When saturated air rises or is forced to ascend, condensation occurs and the heat released as the result of condensation is absorbed by the air. This causes the air to cool at a slower rate than that at which unsaturated air cools. The **Saturated Adiabatic Lapse Rate** is about 1.5°C per 1000 feet. The saturated adiabatic lapse rate, however, shows considerable variation because it is dependent on the rate at which the water vapour is condensing and the figure of 1.5°C must be regarded as an average value only. In actuality, the saturated adiabatic lapse rate can vary from 1°C to almost 3°C.

Understanding and applying the adiabatic lapse rate is important for the pilot. Knowing surface temperature and dewpoint, he is able to determine at what height he might expect the bases of the clouds to be. He is also able to determine at what altitude he might expect to encounter icing conditions. He is able to calculate the temperature at various altitudes.

Let us consider the following situation. The surface temperature is 15°C and the dewpoint is 5°C. The surface elevation is 1500 feet. At what height might the bases of the convective type clouds be expected to be? Knowing that the temperature in a rising column of unsaturated air decreases 3°C per 1000 feet, it is necessary to determine the spread between the surface temperature and the dewpoint and divide that figure by 3. The "spread" is 10°. Ten divided by 3 is 3.3. The bases of the cloud can be expected to be at a height of approximately 3300 feet AGL, or 4800 feet ASL.

At what height might icing conditions be encountered in the cloud? In saturated rising air, the lapse rate averages about 1.5°C per 1000 feet. The base of the cloud is at 4800 feet ASL at a temperature of 5°C. The spread between the dewpoint and freezing is 5°. Five divided by 1.5 is 3.3. The freezing level, therefore, could be expected at about 3300 feet above the bases of the clouds, or at 8100 feet ASL.

What is the temperature at 10,000 feet ASL? The temperature at 4800 feet is 5°C. For the remaining 5200 feet, the temperature decreases 1.5°C per 1000 feet, giving a cooling of 5.2 X 1.5 or 7.8°. The temperature at 10,000 feet would, therefore, be 5° less 8°, or —3°C.

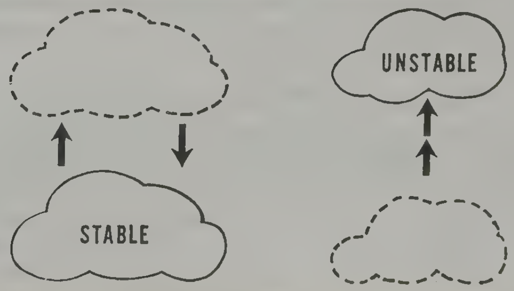
It must be remembered that the temperature within a rising column of air is quite different than the temperature in the surrounding non-rising air. In the surrounding non-rising air, the temperature at 10,000 feet ASL would be determined by applying the normal lapse rate of 1.6°C per 1000 feet.

INVERSION

Normally, the temperature of the atmosphere decreases with height. However, this is not invariably the case. Sometimes warmer air may be found at higher altitude. Such a reversal of normal conditions is known as an **Inversion**. It can occur on a clear night when the cold ground cools the air above it in the lower levels, or when warm air is lifted above colder air over a frontal surface (which will be explained in "**Fronts**", below).

STABILITY

The normal flow of air tends to be horizontal. But distur-



Stable and Unstable Air

bances may cause vertical updrafts or downdrafts to develop. Air that will *resist* upward or downward displacement and tends to *return* to its original horizontal level is said to be **stable.** Air which tends to move *further away* when disturbed is **unstable.** The vertical currents associated with an unstable condition may cause turbulence and, if intensive enough, thunder shower activity.

When air rises it expands and cools — adiabatically. If a mass of rising air (cooling by expansion) is still **warmer** than the air surrounding it, it is **unstable.** If disturbed, it will tend to rise further.

If a mass of rising air is **cooler** than the air around it, it is **stable.** If disturbed, it will tend to sink back to its original level.

The lapse rate in the part of the air which is not rising is one of the most important factors which determines the stability of air. If the lapse rate is steep, there is colder air aloft which will tend to sink to the surface if the air is disturbed and the warm air of the lower levels will rise. If the lapse rate is shallow so that there is only a slight temperature decrease with height or if there is warmer air on top, there will be no tendency for vertical motion to develop.

In the above case, we have considered *masses,* or *hunks* of air which have, for any reason, been displaced upwards. If a **layer** of air becomes warmer in the lower levels or cooler in the upper levels it will have a steep temperature lapse rate. It will therefore become **unstable.** Flying conditions in such a layer can be rough. Turbulence may range from moderate to severe. Clouds if any, may be of the heap type (cumulus or cumulonimbus). Showers or thunderstorms may develop. Other than in clouds or precipitation, however, visibility will be good.

A layer of air which has a small temperature lapse rate will be **stable.** There will be little tendency for vertical currents to develop. Cloud, if present, will be of the layer type, such as stratus, and flying conditions will be smooth. Visibility, however, may be poor. Precipitation, if present, will be steady. Fog may occur.

LIFTING AGENTS

There are five principal conditions that provide the lift to initiate rising currents of air.

1. **Convection.** The air is heated through contact with the earth's surface. The rising columns are usually local and separated by areas of sinking air. They result from unequal heating of different types of land surface and especially from the different surface temperatures of land and water areas.

2. **Orographic Lift.** Air moving up a sloping terrain, such as a mountainside, will continue its upward movement, especially if it is unstable.

3. **Frontal Lift.** When different air masses meet, warm air is forced aloft by the advancing or receding wedge of cold air. (See "**Fronts**" below).

4. **Mechanical Turbulence.** Friction between the air and the ground disrupts the lower levels of the air into a series of eddies. These eddies are usually confined to the lower few thousand feet of the atmosphere but may extend higher if the air is unstable and surface winds are strong.

5. **Convergence.** In a low pressure area, the winds blow across the isobars into the centre of the low. Air accumulates in the centre of the low and the excess air is forced to rise.

VAPOUR TRAILS ("CONTRAILS")

The white vapour, or condensation trails ("Contrails") you see high up in the blue in this age of jet airplanes, owe their origin to two different causes.

1. EXHAUST TRAILS. When the hydrogen and carbon in aviation fuel are burned, the carbon produces a colorless gas, and the hydrogen produces water vapour — both of which are invisible. The latter product of combustion, which comes out of the exhaust, will remain invisible as long as the humidity of the surrounding air has not reached its saturation point. As stated in the section above, warm air can contain much more invisible water vapour than cold air before it becomes saturated. In the extreme low temperatures encountered at very high altitudes, the cold air is incapable of absorbing the excess water vapour coming out of the exhaust. The latter therefore condenses into a visible cloud of water droplets or ice crystals. This is known as an **Exhaust Trail.**

2. WING TIP TRAILS. As we learned in Theory of Flight ("Drag"), vortices, in the form of eddies rotating with a corkscrew motion, come off the tips of an airplane wing in flight. These rapidly rotating vortices have considerable centrifugal force acting outwards, which causes a rarefaction, and therefore an expansion of the air in the middle of the vortex. Air which expands, cools. If the vortex is strong enough, and the humidity of the air high enough, this cooling will cause condensation. The white cloud-like trails which form off the wing tips are known as **Wing Tip Trails.**

AIR MASSES

In the past, the weatherman based his predictions on the weather mainly upon the existence and movement of high and low pressure areas and the wind and weather systems which are associated with them. Today, the whole system of weather forecasting is based upon the properties of Air Masses (of which pressure is only one factor), the changes which occur as an Air Mass moves away from its source, and the weather phenomena which can be predicted along the "Front" where two Air Masses of different properties come in contact.

An **Air Mass** takes on its original properties from the surface over which it has formed. An Air Mass which has formed over the ice and snow surfaces of the Arctic would be cold and dry. An Air Mass lying over the South Pacific would be warm and moist.

An Air Mass which has formed over a large body of water and is therefore moist is referred to as *Maritime Air.* One which originates over a large land area and is therefore dry is referred to as *Continental Air.*

The three main sources of the Air Masses of North America are: (i) The "Arctic Region", which extends from the North Pole south to the permafrost line. (ii) The "Polar Region", which extends south from the permafrost line to where the mean temperature is 10°C. (iii) The "Tropical Region", which lies below Latitude 30°N.

The principal Air Masses of North America are as follows:

Continental Arctic (cA) and **Continental Polar (cP):** Cold dry air masses which originate over the intensely cold ice and snow covered surface of the far north and bring a cold wave when they move south.

Maritime Arctic (mA) and **Maritime Polar (mP):** These are cold air masses which form over the Arctic and acquire moisture as they move south over the cold waters of the North Atlantic and North Pacific oceans. The Maritime Polar Air Mass is air which has moved further out and over the ocean and, through contact with the ocean surface, has become more warm and moist than Maritime Arctic air.

Maritime Tropical (mT): Because the Continent of North America narrows down towards its southern extremity, most of the tropical air in the southern latitudes is in contact with the warm ocean surface and becomes hot and moist. Source regions for Maritime Tropical air are: The Gulf of Mexico, the Caribbean Sea, and the Tropic of Cancer regions of the North Atlantic and North Pacific oceans.

An explanation of Air Mass symbols will be found in **"Weather Map Symbols"** (on the reverse side of the weather map insert).

MODIFICATION OF AIR MASSES

Air masses that form in particular source areas vary in their characteristics from season to season and, as they move away from their source area, they are modified by conditions that affect temperature, humidity and stability in the areas over which they pass. Temperatures may vary considerably within an air mass as the air is warmed while passing over relatively warm surfaces and cooled while passing over relatively cool surfaces. Moisture content may also vary. The air mass will pick up moisture as it passes over lakes, wet ground or melting snow. Moist air passing over a mountain range may lose a great deal of moisture as precipitation as it ascends the western slope of the range. Stability characteristics also may vary considerably. These variations in the properties of a particular air mass during its life are not unusual. As a result, it is impossible to say that a certain weather pattern will always occur in an air mass that is classified, for example, as Continental Arctic.

Nevertheless it is possible to define in broad terms some typical characteristics of cold and warm air masses.

Cold Air Mass	**Warm Air Mass**
Instability	Stability
Turbulence	Smooth Air
Good Visibility	Poor Visibility
Cumuliform Clouds	Stratiform Clouds and Fog
Precipitation: Showers Hail, Thunderstorms	Precipitation: Drizzle

FRONTS

The Troposphere is made up of air masses. The transition zone between two air masses is called a **front.** The interaction of these air masses, along their frontal zones, is responsible for weather changes.

POLAR FRONT

The present day theory which explains the formation of depressions, or lows, was developed by the Norwegians, and is known as the **Polar Front Theory.** It is based on the fact that the polar regions are covered by a mass of cold air and the equatorial regions by a mass of warm air. In the temperate zone, the two air masses meet. Air masses do not usually mix. The transition zone between the two masses is therefore narrow and is called a **Polar Front.**

The air on the northern side (considering the northern hemisphere) of this surface of separation is termed **Arctic and Polar Air.** It is normally cold, and dry. The air on the southern side is termed **Tropical Air.** It is normally warm, and moist.

Due to the difference in the properties of these two air masses, the Polar Front is known as a **Surface of Discontinuity.** Depressions form along this Surface of Discontinuity, the Polar Front, and are the means whereby interchange takes place between the warm and cold air masses.

Along the Polar Front, the cold polar air flows from the north-east towards the south-west on the north side (Fig. 12) while the warm air flows from south-west towards the north-east on the south side. The arrangement is not a stable one but is subject to continual disturbances due to the warm air bulging north and cold air bulging southward. This northward bulge, once having started, continues to develop, the cold air on the northward side swinging round at the back and emphasizing the bulge. (Fig. 13.) This bulge is the new depression (or low pressure area), just born, which normally travels north-eastward along the Polar Front, carrying with it the wind and weather characteristics produced by the interaction of the two different air masses concerned.

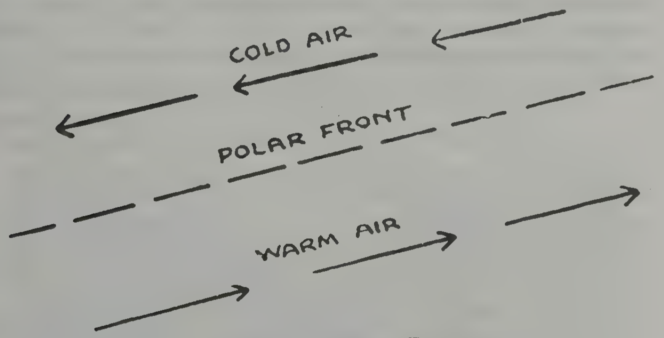


Fig. 12. The Polar Front.

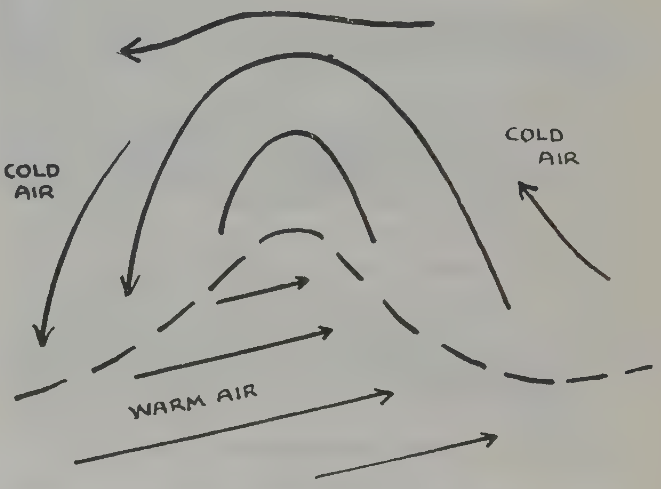


Fig. 13. Bulge in the Polar Front.

TYPES OF FRONTS

Fig. 14 shows the further development of the bulge referred to above. The two currents of air of different properties compounding the depression are clearly shown marked "cold air" and "warm air". The Polar Front has now been bent or broken into two lines marked the "Warm Front" and the "Cold Front."

A COLD FRONT is that part (or parts) of a frontal system along which cold air is **advancing** and is coloured blue on the weather map.

A WARM FRONT is that part (or parts) of a frontal system along which cold air is **retreating** and is coloured red on the weather map.

The area contained within the bulge of the Polar Front is marked "Warm Sector". It will be seen that the warm sector contains the warm or equatorial air concerned in the depression, while the rest of the area covered by the depression is composed of the polar air concerned. The two lines of discontinuity, the warm front, and the cold front, are marked by abrupt changes in wind direction, and temperature.

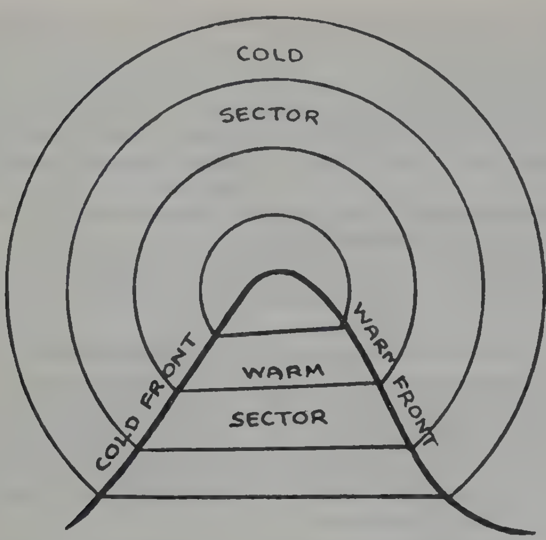


Fig. 14. Development of a Depression showing Isobars.

Note: The isobars (Fig. 14) are bent into the form of a "V" or "trough" at both the warm and cold fronts.

THE WARM FRONT

As a mass of warm air advances on a mass of cold air, the warm air, being lighter, ascends over the cold air in a **long gentle slope.** This rising warm air gives rise to the cloud sequence shown in Fig. 15 ranging from high cirrus, down through altostratus to nimbostratus. Thus the approach of a warm front is marked by a gradual falling ceiling, followed by a long belt of steady rain. The passing of the warm front is marked by a rise of temperature, due to the entry of the warm sector, and the sky becomes relatively clear.

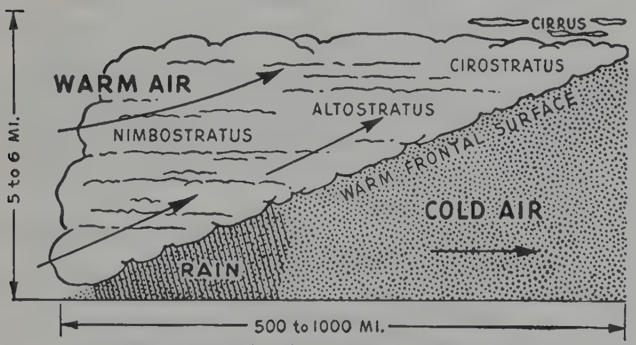


Fig. 15. Vertical Section through a Warm Front.

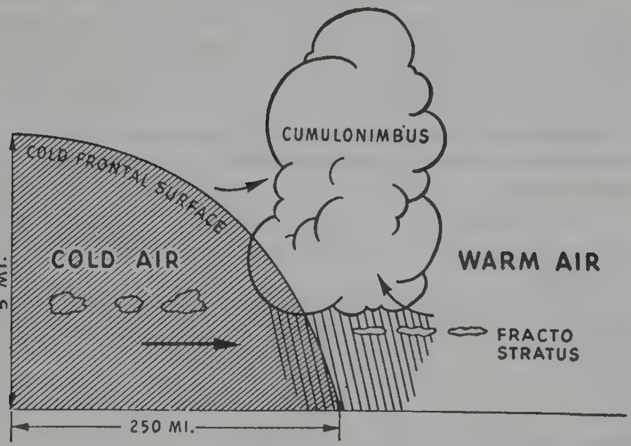


Fig. 16. Vertical Section through a Cold Front.

THE COLD FRONT

When a mass of cold air overtakes a mass of warm air, the cold air **undercuts** the warm air violently. The rapid ascent of the warm air gives rise to cumulo-form cloud with a short period of squally, showery rain, sometimes very heavy and accompanied by thunder. A sharp fall in temperature is also experienced with the passage of the cold front.

THE STATIONARY FRONT

There is generally some part of a front along which the colder air is neither advancing nor retreating. There is no motion to cause the front to move because the opposing air masses are of equal pressure. The surface wind tends to blow parallel to the front and the weather conditions are similar to those associated with a warm front although generally less intense and not so extensive. Usually a stationary front will weaken and eventually dissipate. Sometimes, however, after several days, it will begin to move and then it becomes either a warm front or a cold front.

OCCLUDED FRONTS

With the progress of time, as a depression advances, the cold front gradually overtakes the warm front and lifts the warm sector entirely from the ground. It is simply a case of the cold air catching up with itself as it flows around the depression. Thus only one front remains, which is called an **Occluded Front or Occlusion.** An occluded depression soon commences to fill up and die away.

The cold air, in the distance it has travelled, may have undergone considerable change. Therefore it may **not be as cold** as the air it is overtaking. In this case (**cool** air advancing on **colder** air), the front is known as an **Occluded Warm Front** or a **Warm Occlusion** and has the characteristics of a warm front, with low cloud and continuous rain and drizzle. (Fig. 17.)

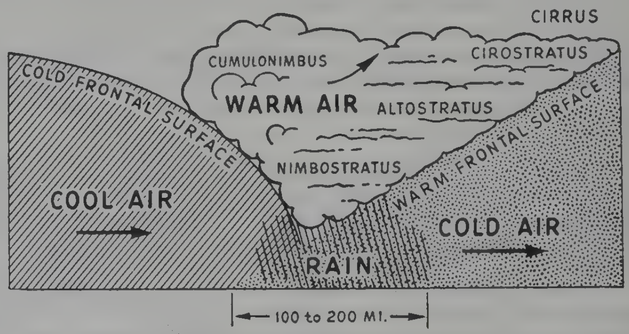


Fig. 17. Vertical Section through a Warm Occlusion.

If the cold air is colder than the air it is overtaking (**cold** air advancing on **cool** air) the front is known as an **Occluded Cold Front** or a **Cold Occlusion.** A cold occlusion has much the same characteristics as a warm front, except that heavy cumulus or cumulonimbus cloud may occur, with the violent turbulence, lightning and icing conditions associated with these clouds.

It will be noted that in the case of an occlusion either warm or cold, **three** air masses are present, a cool air mass advancing on a cold air mass, or a cold air mass advancing on a cool air

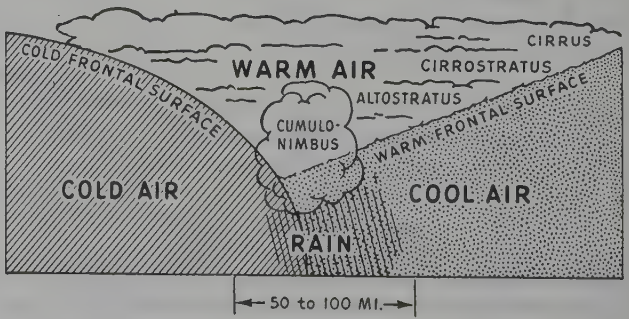


Fig. 18. Vertical Section through a Cold Occlusion.

mass, with, in either case, a warm air mass lying wedge-shaped over the colder air. This wedge shaped mass of warm air is known as a **trowal** in Canada. (In some other countries, it is called an Upper Front.)

FRONTAL WEATHER

The theory of the Polar Front, which, for the sake of simplicity has been described in the form of its original conception, might leave the impression that Depressions form only along some well defined line lying somewhere midway between the Poles and the Equator. Air masses are in a constant state of formation over all the land and water areas of the world. Once formed, they tend to move away from the source regions over which they form. The same frontal processes and phenomena occur whenever a mass of warm air and a mass of cold air come in contact.

There is a widespread impression among pilots that fronts always bring bad weather and that all bad weather is frontal. Actually some fronts have little or no weather associated with them. A slight change of temperature and a windshift may be the only evidence that the front has gone through. And, of course, bad weather can develop without the passage of a front. Fog, for example, generally occurs when no fronts are present and severe thunderstorms may develop in an air mass which has no frontal characteristics.

Another common misconception is that the front is a thin wall of weather. This false idea is perhaps occasioned by the line that indicates a front on a weather map. The line on the map only shows the surface location at which the pressure change, windshift and temperature change occur. The actual weather associated with the front may extend over an area many miles in width, both well ahead and also for many miles behind the actual line on the weather map.

A front itself is actually a transition zone between two large air masses with different properties of temperature and moisture. Each individual air mass may extend over hundreds of thousands of square miles. Everywhere along the boundary of an air mass, where it overrides or undercuts the air mass upon which it is advancing, there is a frontal zone. The frontal weather associated with the front, therefore, can be expected to extend for hundreds of miles along the boundary of the air mass.

Frontogenesis means a front which is *increasing* in intensity.

Frontolysis means a front which is *decreasing* in intensity.

If you examine the diagrams showing fronts on a weather map, you will notice that all fronts lie in regions of lower pressure. The isobars are bent sharply at a front. These two factors are characteristic of all fronts.

WEATHER AT THE COLD FRONT

Cold fronts are not all the same. The weather associated with a cold front may vary from a minor windshift to severe thunderstorms, low ceilings, restricted visibility and violent gusty winds. The severity of the weather is determined by the moisture content and stability of the warm air mass that the cold air mass is undercutting and the speed of the advancing cold front.

A long line of cumulus clouds on the western horizon is usually an indication of an approaching cold front. Sometimes a deck of altocumulus cloud or decks of stratus and stratocumulus extending ahead of the front will mask the main frontal cloud from the view of the high flying or low flying pilot respectively.

Weather Changes

Surface Wind: The wind direction will always **veer** as the front passes. Gustiness may be associated with the windshift.

In flying through a cold front, the windshift may be quite abrupt and occurs at the frontal surface rather than at the front. The windshift is always such that an alteration in course to starboard is required, no matter which way you are flying through the front.

Temperature: On the ground, the temperature may drop sharply as the front passes, but usually it drops gradually. The air immediately behind the front has been warmed in passing over the warm ground. Therefore, it may be several hours before the temperature drops to the true value of the cold air mass.

In flying through a cold front, there will be a noticeable temperature change when passing through the frontal surface.

Visibility: Visibility usually improves after passage of a cold front. If the front is moving fairly rapidly, the width of frontal weather generally is less than 50 miles. If the front is moving slowly, however, flight operations may be affected for many hours.

Pressure: The approach of a cold front is accompanied by a decrease in pressure. A marked rise will be noticed when the front has passed.

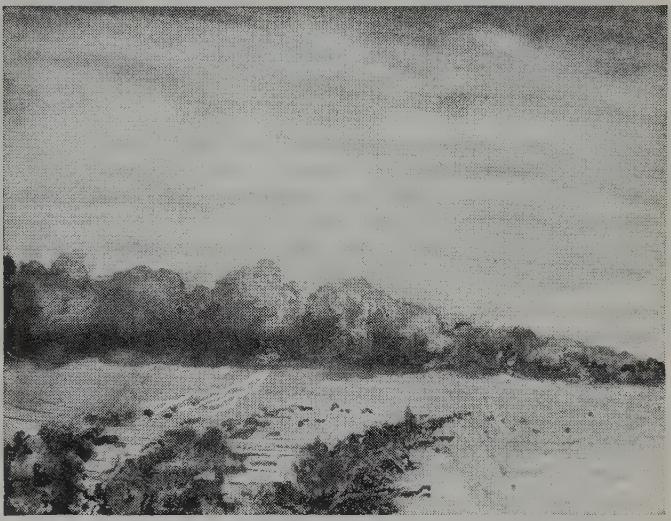


Fig. 19. Line Squall.

Turbulence: Turbulence may be associated with the cold front if it is active, although thunderstorms are not always present. Even in cases where there are no clouds, turbulence may be a problem. As a rule, flight through an active cold front can be expected to be rough.

Precipitation: The frontal rain or snow is usually narrow, especially if it is showery in character.

Icing in the turbulent cumulus clouds can be severe.

Line Squalls

A long line of squalls and thunderstorms which sometimes accompanies the passage of a cold front is called a Line Squall (or Squall Line). The squall is accompanied by a long line of low, black, roller like cloud, which often stretches in a straight line for several hundred miles, and from which heavy rain or hail falls for a short time. Thunder and lightning frequently occur. The squall is also accompanied by a sudden wind change from southerly or south-westerly to north or north-westerly, together with a sudden drop in temperature and a rise in barometric pressure. The actual wind squall lasts only for a few minutes but is often extremely violent, constituting a serious menace both to shipping and to airplanes. The signs indicating the approach of a line squall are unmistakable. Airplanes on the ground should be immediately hangared. Those in the air should at all costs avoid this violent weather phenomenon.

WEATHER AT THE WARM FRONT

Warm front changes are usually less abrupt than cold front changes. The change is also generally very gradual. However, the weather at a warm front is usually more extensive and may cover thousands of square miles.

A wide variety of weather characterizes warm fronts. The weather may even vary along a given front.

High cirrus cloud is the first sign of the approach of an active warm front. Cirrostratus soon follows—the high thin cloud which causes a halo around the sun or moon. The cloud gradually thickens and the base lowers until a solid deck of altostratus/altocumulus covers the area. Low nimbostratus moves in merging with the altostratus with the result that a solid deck of cloud extending from near the surface to 25,000 feet or more covers the whole area. Precipitation is usually heavy.

Weather Changes

Windshift: With the passage of a warm front, the wind will **veer,** but the change will be much more gradual than in the case of a cold front.

When flying through a warm front, the windshift will occur at the frontal surface and will be more noticeable at lower levels. When flying through a warm front, the windshift is such that a course alteration to starboard is necessary.

Temperature: The warm front brings a gradual rise in temperature.

A pilot flying through the frontal surface will notice a more abrupt temperature rise.

Visibility: Low ceilings and restricted visibility are associated with warm fronts and, because warm fronts usually move quite slowly, these conditions persist for considerable time.

When rain falls from the overrunning warm air, masses of irregular cloud with very low bases form in the cold air. Fog is frequently a condition 50 miles ahead of an advancing warm front.

Turbulence: Cumulonimbus clouds are frequently embedded in the main cloud deck and these storms are responsible for the most severe turbulence associated with a warm front. However, these storms and the turbulence they occasion are less severe than those associated with cold fronts. The principal problem with these storms is that they cannot be located by sight since they are embedded in the main cloud cover.

Precipitation: The first precipitation begins in the region where the altostratus layer of cloud is from 8000 to 12000 feet above the ground. As the front approaches, the precipitation becomes heavier. Occasional very heavy precipitation is an indication of the presence of thunderstorms.

Winter Warm Fronts

In winter, when temperatures in the cold air are below freezing and temperatures in the lower levels of the warm air are above freezing, snow and freezing rain can be expected.

Snow falls from that part of the warm air cloud that is high and therefore below freezing in temperature. From the lower cloud, where temperatures are above freezing, rain falls. However, as the rain falls through the cold air (of the cold air mass that the warm air is overrunning), it is supercooled and will freeze on contact with any cold object. This is known as freezing rain (ZR).

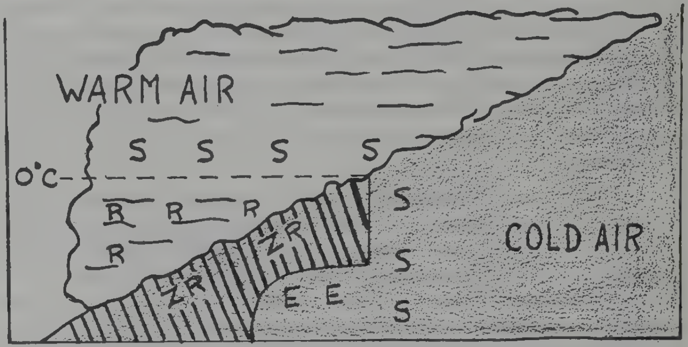


Fig. 20. Precipitation in a Warm Front in Winter.

In the area ahead of the freezing rain, there is a region where the rain falling through the cold air becomes sufficiently supercooled to freeze and falls to the ground as ice pellets (E).

A pilot approaching the frontal surface at higher altitudes may not encounter the ice pellets, but the pilot flying at quite low altitudes can expect to encounter snow, ice pellets and then freezing rain.

Icing is a problem for pilots. Snow is not responsible for icing, unless it is very wet when it can stick to an airplane and form ice. Freezing rain, however, causes a rapid build up of ice. Icing will also be a problem in the cloud layers.

WEATHER AT TROWALS AND UPPER FRONTS

The weather that occurs with a trowal is a combination of cold and warm front conditions. The cloud pattern is similar to that of a warm front ahead of the approaching trowal. Cold front cloud formations will exist behind it.

CLOUDS, PRECIPITATION AND FOG

CLOUDS

Clouds form when the invisible water vapour that is present in the air changes into its visible form as water droplets or ice crystals.

The process by which water vapour changes into water droplets is called **condensation** and occurs when the relative humidity is high, when condensation nuclei are present in the air and when there is cooling of the air.

The level at which water vapour condenses and becomes visible is known as the **Condensation Level.** This level is, in practice, the base of the clouds. If the cloud forms at ground level, it is called fog rather than cloud.

Except at temperatures well below freezing, clouds are composed of very small droplets of water which collect on microscopic water absorbent particles of solid matter in the air (such as salt from evaporating sea spray, dust, and smoke particles).The abundance of these particles, called **condensation nuclei**, on which the droplets form, permits condensation to occur generally as soon as the air becomes saturated. Clouds which form at temperatures well below freezing are usually composed of small particles of ice known as ice crystals which form directly from water vapour through the process of sublimation. When the temperature is between freezing and about -15°C, clouds are composed largely of supercooled water droplets with some ice crystals as well.

(The reason for the existence of liquid water droplets at temperatures well below freezing is complicated. Briefly, it might be said that the freezing process is initiated by the nuclei on which the water droplets form. These nuclei are of different composition and because of their varying chemical characteristics, some of them do not initiate the freezing process until quite low temperatures. The temperature at which a supercooled water droplet freezes depends on its size. Larger droplets freeze at temperatures only slightly below freezing whereas very minute droplets may remain in liquid form until the temperature nears —40°C. Below —40°C, very few, if any, supercooled droplets exist.)

Clouds are formed in two ways. 1) Air, in which water vapour is present, is cooled to its saturation point and condensation occurs. The cooling process will occur as warm air comes in contact with a cold surface or with a surface that is cooling by radiation or as air is affected by adiabatic expansion. 2) Air, without a change in temperature taking place, may absorb additional water vapour until its saturation point is reached with the result that clouds are formed.

Of these, the most common cause of cloud formation is adiabatic expansion, that is, cooling due to expansion brought about by lifting. Stability of the air, of course, is one of the major factors which determines the strength and extent of vertical motion and therefore cloud formation.

The lifting process is initiated by a number of different phenomena.

OROGRAPHIC LIFT

Air blowing against a range of hills or mountains is forced upward, reaches a region of lower pressure, expands and cools. Condensation will occur when the dewpoint is reached. A long bank of cloud from which rain may fall forms on the windward side and the upper part of the hills or mountains. Due to the fact that the rising ground is always in the same place, orographic clouds and rain are typically persistent and usually widespread.

CONVECTION

Warm air rises. Owing to the heating of the ground by the sun, rising currents of air occur. The upward (or downward) movement of air is known as **Convection.** As currents of air rise due to convection, they expand.The expansion is accompanied by cooling. The cooling produces condensation, and a cumulo-form cloud forms at the top of each rising column of air. Further ascent and cooling causes rain. Heavy rain showers and thunderstorms are associated with convection clouds.

FRONTAL LIFT

When a mass of warm air is advancing on a colder mass, the warm air rises over the cold air on a long gradual slope. This slope is called a warm frontal surface. The ascent of the warm air causes it to cool, and clouds are formed, ranging from high cirrus through altostratus down to thick nimbostratus from which continuous steady rain may fall over a wide area.

When a mass of cold air is advancing on a mass of warm air, the cold air undercuts the warm air and forces the latter to rise. The slope of the advancing wedge of cold air is called a cold frontal surface. The clouds which form are heavy cumulus or cumulonimbus. Heavy rain, thunderstorms, turbulence and icing are associated with the latter.

TURBULENCE

When a strong wind blows over a rough surface, or when uneven surface heating occurs, **Turbulence**, in other words **Eddy Motion**, is set up. This motion consists of irregular up and down currents. The air in the upward current cools, and if sufficient moisture is available, and the turbulence is vigorous, condensation may take place in the upper part of the turbulent layer. This results in a deck of cloud such as Stratus and may be accompanied by drizzle, intermittent rain or intermittent snow.

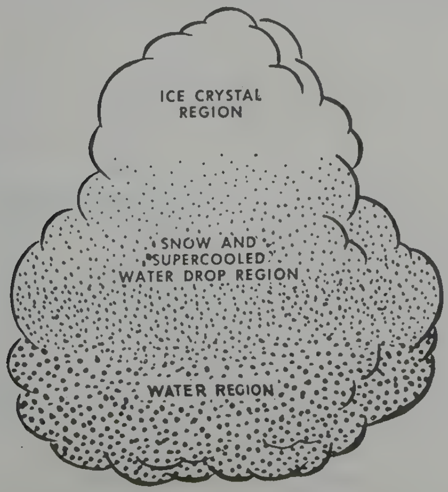


Fig. 21. Regions of a Cloud.

CONVERGENCE

When air piles up over a region as at the centre of a low pressure area, convergence is said to be occurring. The excess air is forced to rise; it expands and cools and when the condensation level is reached, clouds form. Since all fronts lie in regions of low pressure, convergence is often a contributing factor to frontal weather.

PRECIPITATION

Precipitation occurs when the water droplets (visible as a cloud) grow sufficiently in size and weight to fall due to gravity. In clouds with temperatures above freezing, vertical air currents cause the droplets to move about and as a result, they collide with other drops and gradually grow in size, as they absorb those drops with which they collide, and gain momentum until they fall through the air as rain. A single water droplet must grow enormously in order for precipitation to take place. The average raindrop is about one million times larger than a cloud water droplet. This process is known as **coalescence.** Precipitation formed by this method is associated with continental cumulus clouds.

In a stable cloud such as stratus, there is very little vertical motion, not even enough to sustain small water droplets. They frequently escape and drift slowly to the earth. This form of precipitation is called drizzle.

A second mechanism by which precipitation occurs requires that ice crystals and water droplets exist side by side in a cloud at temperatures below freezing. The ice crystals grow at the expense of the water droplets. The droplets tend to evaporate and the resulting water vapour sublimates on the ice crystals. The ice crystals grow in size and weight and will eventually be heavy enough to fall as precipitation. If the temperature below the region of formation is above freezing, the crystals will melt and will arrive at the earth as rain. Precipitation formed by this mechanism occurs in nimbostratus and layer clouds associated with large scale frontal systems.

Precipitation may take many forms.

DRIZZLE

Precipitation in the form of very small drops of water which appear to float is called **drizzle.** At temperatures at or below the freezing level, drizzle will freeze on impact with objects and is known as **freezing drizzle.**

RAIN

Precipitation in the form of large water droplets is called **rain. Freezing rain** is composed of supercooled water droplets that freeze immediately on striking an object which is itself at a temperature below freezing.

HAIL

Observations have revealed the fact that water drops, certainly in the liquid form, can exist with temperatures as low as —40°C. It is clear, then, that small drops can be **supercooled** a long way without freezing.

Most big clouds formed as a result of an upward current of air are divisible into three well defined regions.

First there is the lowest layer where the cloud particles are in the form of water drops.

Next there is a region where some of the water droplets are frozen into ice crystals (snow) but some are still liquid but supercooled.

Third there is the highest region of the cloud where the water vapour sublimates into minute ice crystals.

There is no sharp dividing line between the snow and supercooled water regions. For some distance the ice crystals and supercooled water drops are co-existing. When a supercooled water drop collides with an ice crystal it at once freezes on the latter, imprisoning a little air which causes it to freeze in the form of soft ice. Falling through the supercooled region, more soft ice is deposited on it, increasing its size. The ball of soft ice so formed then falls through the water region. Water freezes on it in the form of hard, transparent ice. Finally the ball falls out of the base of the cloud as a hailstone, a hard, transparent layer of ice covering a soft, white core.

Sometimes gusts carry hailstones back up to the top of the cloud, in which case the whole process is repeated, perhaps several times. In this way, very large hailstones are formed.

The vertical gusts which produce very large hailstones may have speeds in excess of 100 mph.

The conditions which produce hail are very similar to those in which thunderstorms originate. Hence hail is often encountered in a cumulonimbus thundercloud.

SNOW PELLETS (SOFT HAIL)

If the water region lying below the supercooled region of the cloud is not of great depth, the hailstone does not acquire the hard, transparent covering and arrives at the ground as the original soft, white ice. It is then known as a snow pellet or soft hail.

SNOW

In the formation of **snow,** the invisible water vapour in the air sublimates directly into ice crystals, without passing through any intermediate water stage. Snow flakes are formed of an agglomeration of ice crystals and are usually of a hexagonal or star like shape. **Snow grains** are tiny snow crystals that have acquired a coating of rime. They fall from non-turbulent clouds.

ICE PRISMS

Ice prisms are tiny ice crystals in the form of needles. They may fall from cloud or from a cloudless sky. They exist in stable air masses and at very low temperatures.

ICE PELLETS (SLEET)

Ice pellets are formed by the freezing of raindrops. They are hard transparent globular grains of ice about the size of raindrops. They generally rebound when striking the ground.

FOG

Fog is, in fact, a cloud, usually stratus, in contact with the ground. It forms when the air is cooled below its dewpoint, or when the dewpoint is raised to the air temperature through the addition of water vapour.

To form a water drop in the atmosphere (the basis of fog formation), there must be present some nucleus on which the water may form. Dust, salt, sulphur trioxide, smoke, etc., provide this function.

Given a sufficient number of condensation nuclei, the ideal conditions for the formation of fog are high relative humidity and a small temperature dewpoint spread and some cooling process to initiate condensation. Light surface winds set up a mixing action which spreads and increases the thickness of the fog. In very still air, fog is unlikely to form. Instead dew will collect.

Fogs are most likely to occur in coastal areas where moisture is abundant. Because of the high concentration of condensation nuclei, they are also common in industrial areas.

Smoke and dust in the air over large cities produce the "pea soup" fogs characteristic of London and other large industrial centres. The carbon and dust particles cause such fogs to be dark. Otherwise, when composed of water drops only, fogs are white in colour.

Fog is usually dissipated by sunlight filtering down through the fog or stratus layer. This results in heating from below.

TYPES OF FOG

RADIATION FOG is formed on clear nights with light winds. The ground cools losing heat through radiation. The air in direct contact with the earth's surface is cooled. If this air is moist and the temperature is lowered below the dew point, fog will form. This type of fog is commonly called "ground fog", since it forms only over land. Radiation fog normally dissipates within a few hours after sunrise as the temperature begins to rise.

ADVECTION FOG is caused by the drifting of warm damp air over a colder land or sea surface. It occurs most frequently in coastal regions and can be very persistent, forming both during the day and night and lasting for lengthy periods.

UPSLOPE FOG is caused by the cooling of air due to expansion as it moves up a slope. A light upslope wind is necessary for its formation.

STEAM FOG forms when cold air passes over a warm water surface. Evaporation of the water into the cold air occurs until the cold air becomes saturated. The excess water vapour condenses as fog. Steam fog occurs over rivers and lakes, especially during the autumn.

PRECIPITATION-INDUCED FOG is caused by the addition of moisture to the air through evaporation of rain or drizzle. This type of fog is associated mostly with warm fronts. The rain falling from the warm air, evaporates and saturates the cooler air below.

ICE FOG forms in moist air during extremely cold calm conditions. The tiny ice crystals composing it are often called needles.

HAZE

Haze is composed of very small water droplets, dust or salt particles so minute that they cannot be felt or individually seen with the unaided eye. Haze produces a uniform veil that subdues visibility. Against a dark background it has a bluish tinge. Against a bright background it has a dirty yellow or orange hue.

Haze is a problem only in very stable air. In unstable conditions, the particles scatter.

CEILING AND VISIBILITY

The CEILING is the height above **ground or water** of the lowest layer of clouds and is reported as BKN (broken), OVC (overcast) or X (obscured). See also **"Aviation Weather Reports".**

Restrictions to visibility would include cloud, precipitation, fog, haze, smoke, blowing dust or snow. Blowing snow, dust and sand can produce very poor visibility conditions. Blowing snow can be responsible for optical illusions. Precipitation, in the form of rain, snow and drizzle, appreciably reduces visibility. Drizzle which occurs in stable air is often accompanied by fog or smog.

VISIBILITY means the distance at which prominent objects may be seen and identified by day, and prominent lighted objects by night.

FLIGHT VISIBILITY is the average range of visibility forward from the cockpit of an airplane in flight.

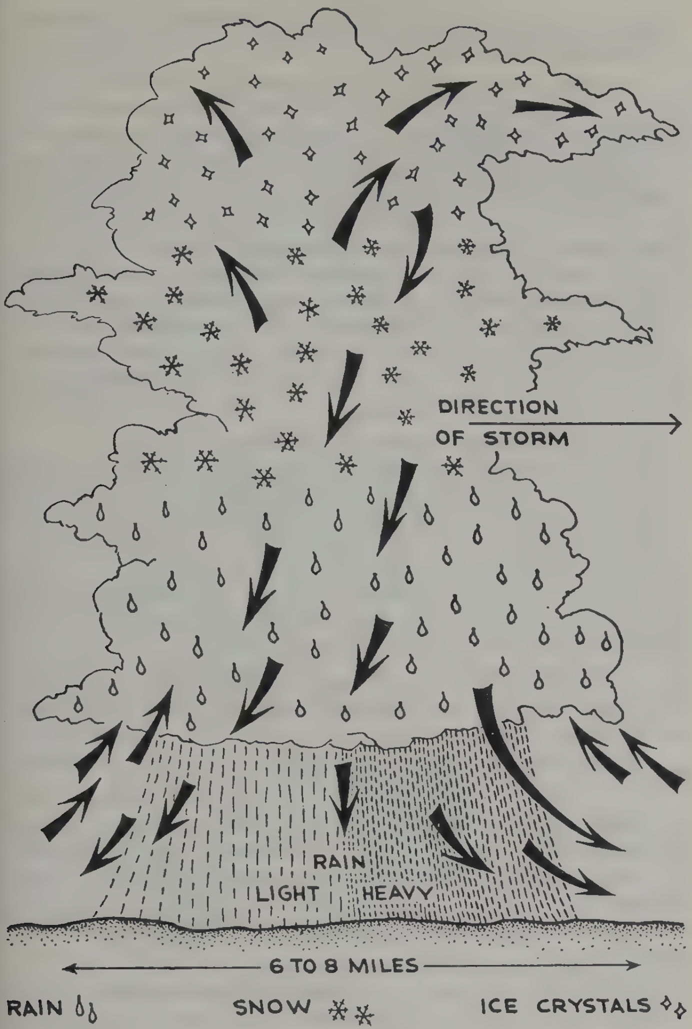
GROUND VISIBILITY is the visibility at an airport, as reported by an accredited observer.

PREVAILING VISIBILITY is the distance at which objects of known distance are visible over at least half the horizon. It is reported in miles and fractions of miles.

RUNWAY VISIBILITY is the distance towards the horizon an observer, near the end of the runway, can see in miles and fractions of miles.

RUNWAY VISUAL RANGE represents the distance a pilot touching down at the threshold of the runway can expect to see when looking down the runway. Reported in hundreds of feet.

APPROACH LIGHT CONTACT HEIGHT is the height at which a pilot will be able to see the approach lights. (Based on the pilot's Slant Visual Range.)



Thunderstorm Cell in Mature Stage.

THUNDERSTORMS

A thunderstorm is a weather phenomenon whose passage creates extremely serious hazards to flying. It occurs when an air mass becomes unstable to the point of violent overturning. Such unstable atmospheric conditions may be brought about when air is heated from below or forced to ascend the side of a mountain or lifted up over a frontal surface. The resulting buoyancy causes air which is warmer than its environment to push up in the form of convection currents, like drafts up a chimney flu.

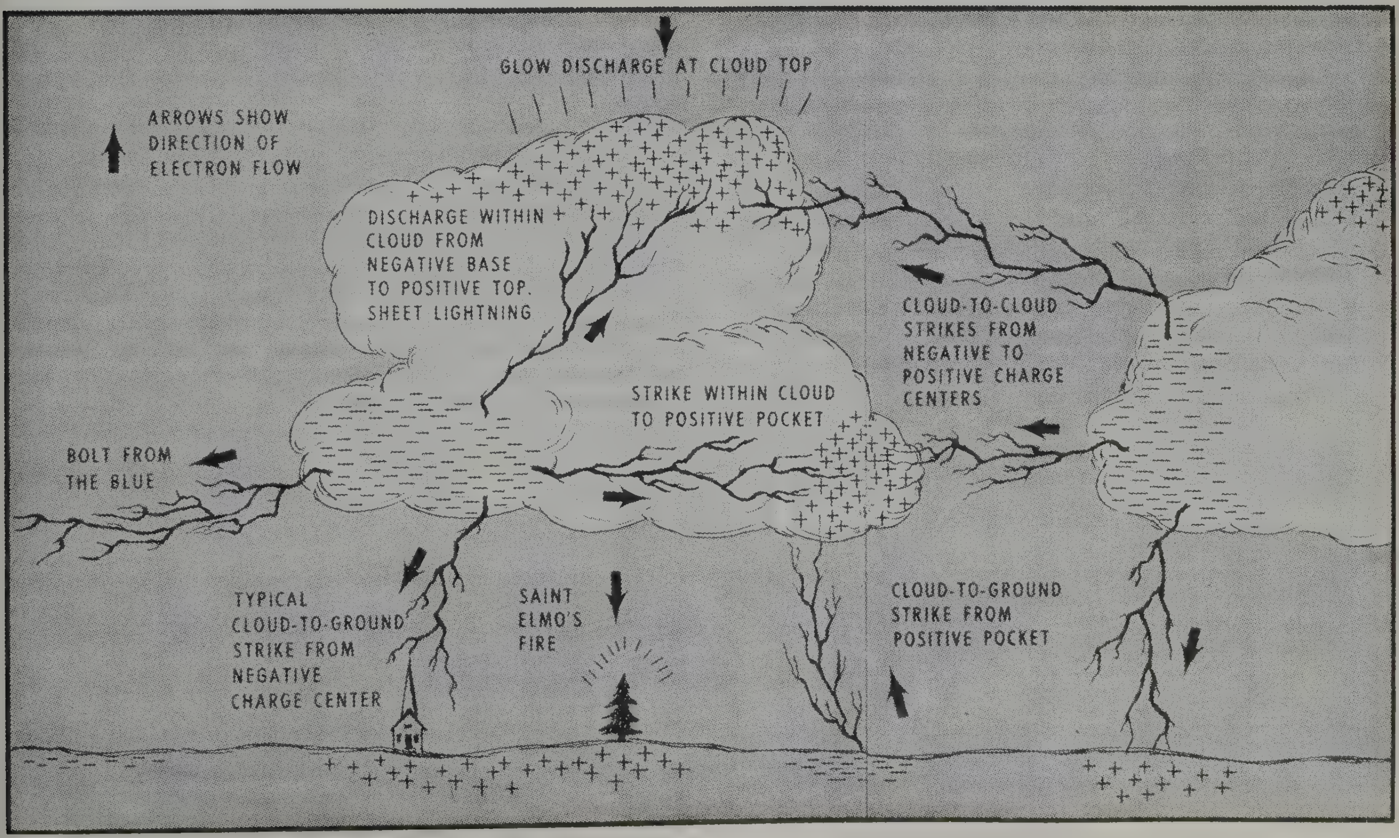
If a mass of superheated moist air rises rapidly, an equal amount of cooler air rushes down to replace it.

When these conditions lead to the development of a thunderstorm, the area in which the rising and descending currents are active is called a **Thunderstorm Cell.** A thunderstorm may be composed of a number of such cells. Every thunderstorm begins life as a cumulus cloud. High humidity, unstable conditions and strong updrafts are responsible for turning it into a thunderstorm.

The "build-up" of a towering cumulonimbus thunderstorm may reach heights as great as 60,000 ft. The updrafts may attain speeds of 6000 ft. per min. Downdraft speeds are not as great, but speeds of 2000 ft. per min. are not uncommon. At first the downdrafts occur only in the middle and lower regions of the cell. Violent turbulence is associated with the up and down drafts.

The appearance of precipitation on the ground is evidence that the thunderstorm cell is in its mature stage. The mature stage lasts for about 15 to 30 minutes and then the cell begins to dissipate. The downdraft spreads throughout the whole area of the cell with the exception of a small portion at the top where the updrafts still occur. The rainfall gradually ceases. The top of the cell spreads out into the familiar anvil structure.

Gusts within a thunderstorm are thought to result from the shear zones associated with the updrafts and downdrafts. They are small swirling eddies of exceedingly turbulent air superimposed upon the large scale drafts. (Shear zones are similar to wind shear.)


GLOW DISCHARGE AT CLOUD TOP
ARROWS SHOW DIRECTION OF ELECTRON FLOW
DISCHARGE WITHIN CLOUD FROM NEGATIVE BASE TO POSITIVE TOP. SHEET LIGHTNING
CLOUD-TO-CLOUD STRIKES FROM NEGATIVE TO POSITIVE CHARGE CENTERS
STRIKE WITHIN CLOUD TO POSITIVE POCKET
BOLT FROM THE BLUE
TYPICAL CLOUD-TO-GROUND STRIKE FROM NEGATIVE CHARGE CENTER
SAINT ELMO'S FIRE
CLOUD-TO-GROUND STRIKE FROM POSITIVE POCKET

Lightning flashes are evidence of the vast quantity of electrical energy released in a thunderstorm. The lightning is due to the separation of positive and negative charges in a cloud, the flash being the discharge between them, or between the cloud and the ground.

Thunder is the noise which accompanies a lightning flash. It is attributed to the vibration set up by the sudden heating and expansion of the air along the path of the lightning flash.

Hail may be regarded as one of the worst hazards of thunderstorm flying. It usually occurs during the mature stage of cells having updrafts of more than average intensity. The formation of hail has been covered earlier in this section.

Icing in a thunder cell is encountered at or above the freezing level in the areas of heaviest turbulence during the mature stage of the storm. The altitudes within a few thousand feet of the freezing level, above or below, are especially dangerous.

Snow can be found at all levels above the freezing level, and presents a unique flying problem. The ''penetration shock'' of a wing can cause snow accumulation on the leading edge of a wing to form rime ice.

The barometric pressure ahead of a thunderstorm falls abruptly as the storm approaches, then rises quickly when the rain comes, and returns to normal when the storm subsides. Occasionally after a storm the pressure falls below normal, then rises to near normal again. All this in a matter of 10 to 15 minutes.

The dangers of flying in or close to a thunderstorm are:

1. Turbulence. Thunder cell drafts may be strong enough to displace an aircraft up or down vertically as much as 2000 to 6000 feet. Gust loads can be severe enough to stall an aircraft flying at rough air (maneuvering) speed or cripple it at design cruising speed. Maximum turbulence usually occurs between 12,000 and 20,000 feet and is most severe in clouds of the greatest vertical development. Severe turbulence is present not just within the cloud but even in clear air in proximity to the cloud and above it.

2. Lightning. Static electricity may build up in the airframe, interfering with operation of the radio and affecting the behaviour of the compass. Trailing antennas should be wound in. ''Lightning blindness'' may affect the crew's vision from 30 to 50 seconds, making instrument reading impossible during that brief period. Lightning strikes of aircraft are not uncommon and pose special hazards. Structural damage is possible. The solid state circuitry of modern avionics is particularly vulnerable to lightning strikes. Electrical circuits may be disrupted. The possibility of lightning igniting the fuel vapour in the fuel cells is also considered a potential hazard.

3. Hail. Hailstones are capable of inflicting serious damage to an airplane. The maximum altitude at which hail occurs is 10 to 15 thousand feet.

4. Icing. Heaviest icing conditions occur above the freezing level where the water droplets are supercooled. Icing is most severe during the cumulus stage of the thunderstorm.

5. Pressure. Rapid changes in barometric pressure associated with the storm cause altimeter readings to become very unreliable.

6. Wind. Abrupt changes in windspeed and direction present a hazard during take-off and landing in advance of a thunderstorm. Gusts in excess of 90 mph have been observed.

Because of the severe hazards enumerated above, attempting to penetrate a thunderstorm is asking for trouble. In the case of light airplane pilots, the best advice on how to fly through a thunderstorm is summed up in one word — DON'T. Detour around storms as early as possible when encountering them enroute. Avoid landing or take-off at any airport in close proximity to an approaching thunderstorm or squall line. If, however, you are piloting a transport type airplane, and circumstances make it a ''must'', the following few simple rules may help you survive the ordeal:

Go straight through a front — not across it.

Hold a reasonably constant heading that will get you through the storm cell in the shortest possible time.

Before entering the storm, reduce airspeed to the airplane's maneuvering airspeed to minimize structural stresses.

Turn cockpit lights full bright. (Helps to minimize risk of ''lightning blindness''.) Check pitot head and carburetor heat. Fasten seat belts. Secure loose objects in cabin.

Try to maintain a constant attitude and power setting.(Vertical drafts past the pitot head and clogging by rain cause erratic airspeed readings.)

Avoid unnecessary maneuvering. (To prevent adding maneuver loads to those already imposed by turbulence.)

Determine the freezing level and avoid the icing zone. Avoid dark areas of the cell, and at night those areas of heavy lightning.

Do not use the autopilot. It is a constant altitude device and will dive the airplane to compensate for updrafts, causing excessive airspeed, or climb it in a downdraft, creating the risk of a stall.

If forced to fly around a thunderstorm, it is better to fly around the **right** side of it. The wind circulates anti-clockwise and you will get more favorable winds.

Do not attempt to go through a narrow ''clear space'' between two thunderstorms. The turbulence there may be more severe than through the storms themselves. If the clear space is a mile or more in width, however, it may be safe to attempt to fly through the centre. Always go through at the highest possible altitude.

ST. ELMO'S LIGHTS

If an airplane flies through clouds in which positive charges have been separated from negative charges, it may pick up some of the cloud's overload of positive charges. Weird flames may appear along the wings and around the propeller tips. These are called **St. Elmo's Lights.** They are awe-inspiring, but harmless. If the airplane flies in the vicinity of a cloud where negative charges are concentrated, its positive overload may discharge into the cloud. In this case, it is the airplane which *strikes the cloud* with lightning!

ICING

When an airplane, **while flying at a level where the temperature is at or below freezing,** ''strikes'' a supercooled water droplet, the droplet will freeze and adhere to the airplane. Dangerous icing can occur in cloud, freezing rain, or freezing drizzle.

The cloud in which icing most frequently occurs in winter is stratocumulus, but the heaviest deposits are encountered in cumulus and cumulonimbus. Clouds composed of ice crystals (such as cirrus) do not present an icing hazard. (The ice crystals do not adhere to the wing.)

The smaller the water drop, the less distance it will spread back over the wing before freezing. Hence the more dangerous types of icing are encountered in dense clouds, composed of heavy accumulations of large drops, and in rain.

Ice collects on and seriously hampers the function of not only wings and control surfaces and propellers, but also windscreens and canopies, radio antennas, pitot tubes and static vents, carburetors and air intakes. Turbine engines are especially vulnerable. Ice forming on the intake cowling constricts the air intake. Ice on the rotor and stator blades affects their performance and efficiency and may result in flame out. Chunks of ice breaking off may be sucked into the engine and cause structural damage.

Generally, the first sign that icing has commenced is the appearance of a thin coating on the windshield, sometimes preceded by frosting. This can occur on take off and landing and with sufficient rapidity to obscure the runway and other landmarks during a critical time in flight.

Icing of the propeller generally makes itself known by a slow loss of power and a gradual onset of engine roughness. The ice first forms on the spinner or propeller dome and then spreads to the blades themselves. Ice customarily accumulates unevenly on the blades, throwing them out of balance. The resulting vibration places undue stress on the blades and on the engine mounts, leading to their possible failure.

If the propeller is building up ice, it is almost certain that the same thing is happening on the wings, tail surfaces and other projections. The weight of the accumulated ice is less serious than the disruption of the airflow around the wings and tail surfaces. The ice changes the airfoil cross section and destroys lift, increases drag and raises the stalling speed. Landing approaches and landing itself can be particularly hazardous under icing conditions. Pilots should use more power and speed than usual when landing an ice-laden airplane.

If ice builds up on the pitot tube and static pressure ports, flight instruments may cease operating. Altimeter, airspeed, rate of climb and turn and bank would be affected.

Ice on radio antennas can impede VOR reception and destroy all communications with the ground.

Note: Carburetor icing may occur in clear air at higher than freezing temperatures. This subject is examined in the Chapter on **Aero Engines**

TYPES OF ICING

The three main types of ice accretion, in order of their hazard to flying, are as follows:

CLEAR ICE

A heavy coating of glassy ice which forms when flying in dense cloud or freezing rain is known as clear ice. It spreads, often unevenly, over wing surfaces, propeller blades, aerials, etc. The danger is great owing to (i) The loss of lift, because of the altered wing camber, (ii) The increase of drag on account of the enlarged profile area of the wings, (iii) The weight of the large mass of ice which may accumulate in a short time, and finally (iv) The vibration caused by the unequal loading on the wings, and the blades of the propeller(s). When large blocks break off, the vibration may become severe enough to seriously impair the structure of the aircraft. When mixed with snow or sleet, clear ice may have a whitish appearance. (This was once classified as ''Rime-glazed'' but it is now considered to be a form of clear ice.)

RIME ICE

An opaque, or milky white, deposit of ice is known as rime. It accumulates on the leading edges of wings and on antennas, pitot heads, etc. Forms when flying through filmy clouds. The deposit has no great weight, but its danger lies in the aerodynamic alteration of the wing camber and in choking the orifices of the carburetor and instruments.

FROST

A white semi-crystalline frost which covers the surface of the airplane forms in clear air by the process of sublimation. This has little or no effect on flying but may obscure vision by coating the windshield. It may also interfere with radio by coating the antenna with ice. Generally forms in clear air when a cold aircraft enters warmer and damper air during a steep descent.

Frost which forms on the wings when an aircraft is standing on the ground, however, should be removed, as this will interfere with take-off. Snow or moisture should also be removed since this may freeze to the surface while the airplane is taxying out for take-off. (The heat loss due to the forward speed of the airplane can be sufficient to cause congelation).

PROTECTION FROM ICING

Modern transport airplanes are fitted with various systems designed to prevent ice from forming (anti-icers) or to remove ice after it has formed (de-icers).

1. Fluids. There are fluids which are released through slinger rings or porous leading edge members to flow over the blades of the propellers and the surfaces of the wings. Essentially a fluid is an anti-icing device since it makes it difficult for ice to form.

2. Rubber Boots. Membranes of rubber are attached to the leading edges. They can be made to pulsate in such a way that ice is cracked and broken off after it has already formed. This is a de-icing device.

3. Heating Devices. Heating vulnerable areas is a method for preventing the build-up of ice. Hot air from the engine or special heaters is ducted to the leading edges of wings, empennages, etc. Electrically heated coils protect pitot tubes, propellers, etc.

Few single engine airplanes, or even light twin-engine types incorporate any means of ice prevention. A fews tips for pilots flying airplanes in this category will therefore be in order.

When ice formation is observed in flight there is only one certain method of avoiding its hazards — and that is to get out of the ice-forming layer as quickly as possible. This may be done by climbing above the ice forming zone — which obviously would require an airplane having good performance and fitted with radio and proper instruments for flying ''over the top''. The first alternative would be to descend and fly ''contact'' below the ice forming zone. The advisability of this course would depend on the ceiling and visibility along the route at the lower level concerned.

Prompt action on the radio is important when icing starts. Information about the latest weather for altitudes above and below will help the pilot to make the decision on what action to take.

The final alternative would be to turn back, or, if the accumulation of ice had already become serious, to make a forced landing immediately.

In any event, the decision must be made rapidly since once ice has commenced to form, the condition may become critical in a matter of approximately six minutes.

Pilots flying in light airplanes which are not fitted with an outside air temperature gauge will be well advised to have one installed.

With the advent of the jet age, the problem of icing has taken on some surprising new aspects. At one time, the pilots of airplanes flying through high cirrus clouds did not worry about ice forming on the airplane as cirrus clouds are composed of ice crystals rather than water droplets. With the increased speeds of which jet airplanes are capable, the heat of friction is sufficient to turn the ice crystals in the cloud to liquid droplets which subsequently freeze to the airplane.

WEATHER SIGNS

Look for cloudy unsettled weather when

The barometer is falling.

The temperature at night is higher than usual.

The clouds move in different directions at different levels.

High thin white clouds (cirrus) increase. A large ring appears around the sun or moon and stays there until the overcast clouds thicken and obscure the sun or moon.

Summer afternoon clouds darken.

Look for steady precipitation when

There have been signs of unsettled weather.

The wind is south or southeast, the pressure falling. Rain (or snow) within a day if pressure falling slowly. If falling rapidly, rain soon with winds increasing.

The wind is southeast to northeast, the pressure falling. Rain (or snow) soon.

Thunderclouds developing against a south or southeast wind.

Look for showers when

Thunderclouds develop in a westerly wind.

Cumulus clouds develop rapidly in the spring or summer early afternoon.

Look for clearing weather when

The barometer rises.

The wind shifts into the west or northwest.

The temperature falls.

Look for continued bright weather when

You can look directly at the sun when it sets like a ball of fire.

The barometer is steady or slowly rising.

Cloudiness decreases after 3 p.m. or 4 p.m.

Morning fog breaks within two hours after sunrise.

There is a light breeze from the west or northwest.

There is a red sunset.

Look for higher temperatures when

The barometer falls. In summer a falling barometer may indicate cloudy weather which will be cooler than in clear weather.

The wind swings away from the north or the west.

The morning sky is clear, except when the barometer is high or is rising in winter-time, or if the wind is strong from the north or west.

Look for lower temperatures when

The wind swings from the southwest into the west, or from the west into the northwest or north.

When skies are clearing—(although clearing skies in the morning will likely mean warmer weather by afternoon, particularly in the summer).

In the winter, the barometer rises.

Snowflurries occur with a west or north wind.

Pressure is low and falling rapidly, wind east or north-east and backing slowly into north. (The fall in temperature will be gradual.)

WEATHER INFORMATION

WEATHER CHARTS

Weather maps are available in all weather offices where they are received over facsimile machines which reproduce the maps prepared at the Central Meteorological Analysis Office. They are used by meteorologists to give briefings to pilots. Along with the teletype weather reports and forecasts, they provide a comprehensive picture of the weather.

SURFACE WEATHER CHARTS

Surface Weather Charts are issued in all countries to show the state of the weather on the date and hour of publication of the map.

The construction of the weather map, so far as the representation of high and low pressure areas, with their accompanying wind systems, temperatures and frontal conditions will be more readily understood by reference to the sections **Isobars, High and Low Pressure Areas, Air Masses** and **Fronts** which were discussed in the preceeding pages of this Chapter.

A typical Surface Weather Chart prepared by the Canadian Meteorological Service is reproduced as an insert in the **Examination Guide** at the end of the book. This chart depicts the surface weather at a given time for all of Canada and the northern United States. The information used to compile such a map is received from weather stations all over the continent who make hourly reports. The charts themselves are issued eight times a day at three hour intervals. However, it is several hours after the information is received before the charts can be prepared and distributed, so that they are always several hours out of date when received at the weather office. The time of the observations on which the chart is based is indicated in the title box on the corner of the chart.

Reporting stations are marked by circles and weather information is placed around the station circle in a standard pattern called a **station model.** All of the symbols used on a weather chart are depicted and explained on the reverse side of the weather map insert.

UPPER LEVEL CHARTS

Upper Level Charts are similar in construction to surface charts, except that they show flow patterns aloft. The Upper Level Chart is expressed as a **constant pressure level in millibars.** The 850 mb Upper Level Chart, for example, would represent the weather at an average height of approximately 5000 feet MSL.

Upper Level Charts are prepared for 850, 700, 500 and 300 millibars (representing on the average the 5000 ft, 10,000 ft, 18,000 ft and 30,000 ft levels). These charts are useful to the pilot since, used in conjunction with surface weather charts, they give a picture of the extent of weather systems, cloud levels, thunderstorms, rain, snow, etc. The solid lines on an Upper Level Chart connect areas of equal pressure and are called **contour lines** rather than isobars as they are called on surface charts. Dashed lines are isotherms, connecting areas of equal temperature. Fronts are indicated on Upper Level Charts only when they extend up to the pressure level of the chart and appear usually only on the 850 and 700 millibar charts. Information from a reporting station is indicated as on a surface chart but is called a **plotting model** rather than a station model.

PROGNOSTIC CHARTS

Prognostic Weather Charts (Progs) are issued to show what the weather map is expected to look like, a specified number of hours hence. They are actually graphic forecasts of the expected movement of high and low pressure areas, with their accompanying weather systems, and hence are valuable to a pilot in predicting changes which may occur before his actual time of departure or during the progress of his flight.

Upper Level Prognostic Charts, like their surface counterparts, are useful in anticipating weather conditions which may be expected to exist at some later specified time. Like Upper Level Charts, they are prepared for the various pressure levels.

The chart in the lower left hand corner of the weather chart insert is a Prognostic Chart of the flow pattern expected to exist 24 hours hence. The solid lines, numbered 1008, 1016, etc. (meaning 1008 and 1016 millibars) are isobars, or lines drawn through points of equal barometric pressure. The broken lines, numbered 540, 570 etc. (meaning 5400 and 5700 meters) represent 500 millibar contours. These are lines drawn through all points where a pressure of 500 mbs occurs at the same height above mean sea level. For example, along the 570 contour line, the 500 millibar pressure level would be found at a height of 5700 meters (roughly 18,500') MSL.

SIGNIFICANT WEATHER CHARTS

Significant weather charts are prepared for both low level (700 to 500 millibars) and high level (500 to 150 millibars) weather. They are issued four times each day. They forecast the location of frontal and pressure systems and areas and type of precipitation. Significant weather areas are outlined by scalloped or broken lines and the type of significant weather is indicated using standard abbreviations or symbols. Areas of clear air turbulence (CAT) are outlined with heavy broken lines. Types of clouds associated with significant weather are entered with bases and tops indicated in hundreds of feet. The 0°C isotherm is indicated by dashed lines.

INTERPRETING THE WEATHER MAP

In the insert reproduction of the Weather Map referred to above, note the frontal pattern, the distribution of pressure, and the general circulation of the wind. The following observations are a few of the many and varied deductions that a pilot might make by studying the weather map.

The cold front lying over the Maritime Provinces and Eastern Atlantic seaboard is weakening and will likely disappear as the cold arctic air (cA)—indicated by station temperatures behind the front—moves over the warmer water surface. The broken line portion of the front indicates "Frontolysis", meaning a front which is decreasing in intensity. The "Prog" chart in the lower left hand corner indicates that the front is expected to dissipate within the next 24 hours.

The Prognostic Chart (which is a forecast of the weather 24 hours later than the Weather Map) indicates that the low pressure area lying over Wisconsin at 00:00Z on 9 October will have moved over Michigan by 00:00 on 10 October and that the high pressure cell over Quebec will have moved northeast over Labrador.

There is an area of precipitation northeast of the low pressure centre lying over Wisconsin. Both drizzle and snow are falling. (Areas of precipitation are shaded on weather charts). Temperatures show that the freezing level is close to the surface. It may be assumed that there will be an icing hazard associated with this storm. The wise pilot will check with the forecaster as to this possibility. The broken lines on the Prognostic Chart show the flow pattern at 500 mb indicating that there are strong southwest winds above the precipitation area.

AVIATION WEATHER REPORTS (SEQUENCES)

An Aviation Weather Report (Sequence) is a statement of weather conditions actually existing at a particular place at a given time. They are taken hourly by trained observers at hundreds of stations throughout Canada and the United States. The sequence in which weather data is transmitted in code by teletype is as follows:

Station Identification: Type of Report: Sky Condition and Ceiling: Visibility: Weather and Obstructions to Vision: Sea Level Pressure: Temperature and Dewpoint: Wind: Altimeter Setting: Clouds and Obscuring Phenomena (Can): Runway Visual Range (if applicable): Coded Pireps: Remarks: Pressure Tendency.

The Aviation Weather Reports describe the existing weather conditions at specific times and at specific stations. They do not, therefore, give the complete weather picture. Between stations that are a hundred miles apart, the weather can be drastically different than that reported at either station. In addition, weather conditions can change very quickly and be quite different from the condition reported at a particular airport in the time it takes you to fly there.

For the full weather picture, consult the reports over several hours to determine the either improving or deteriorating trend and also consult the forecasts.

SYMBOLS USED IN WEATHER SEQUENCES

Station Identification

Weather reporting stations are assigned three letter identifications in both Canada and the United States. In the U.S., the letters are an abbreviation of the airport name, as, for example, "PIT" for Pittsburgh. In Canada, the second and third letters identify the airport. The first letter indicates the type of weather reporting station.

Y — reporting station co-located with an airport.
W — reporting station not co-located with an airport
U — reporting station co-located with a radio beacon.

For example, YOW — Ottawa — weather reporting station is co-located with the airport.

WMN — Mount Forest, Ontario — weather reporting station is not located at an airport.

Sky Condition

CLR	Clear	X	Obscured
SCT	Scattered clouds	—X	Partially obscured
BKN	Broken clouds	—	Thin
OVC	Overcast		

Ceiling

M	Measured	W	Indefinite
A	Aircraft	P	Precipitation
B	Balloon	E	Estimated

Multiple layers of cloud, including the ceiling layer, are stated in hundreds of feet *above ground* with the final "00" of the figure omitted, e.g.: "4" means 400 feet. Higher layers follow lower layers in ascending order. The ceiling figure is always preceded by a letter indicating the nature and method of determining the ceiling. For example, "E30" means Ceiling Estimated, 3000 feet. The letter "V" following the ceiling figure means that the ceiling is Variable.

Example (Sky Condition and Ceiling): 10 SCT M30 BKN 100 OVC means: 1000 ft. scattered . . . ceiling measured 3000 ft. broken . . . 10,000 ft. overcast.

Visibility

The horizontal visibility is reported in figures representing statute miles and fractions of miles. e.g. "10" means 10 miles. "¼" means one quarter of a mile. The letter "V" following the visibility figure in miles means "Visibility variable". (If the visibility is 6 miles or less, the reason is always given under the "State of Weather" or "Obstructions to Vision".)

State of Weather

R	Rain	E	Ice pellets (sleet)
IC	Ice crystals	A	Hail
S	Snow	AP	Small hail
SG	Snow grains	T	Thunderstorm
SP	Snow pellets	SW	Snow showers
ZR	Freezing rain	RW	Rain showers
L	Drizzle	T+	Heavy thunderstorm
ZL	Freezing drizzle	EW	Sleet (ice pellets) showers

TORNADO is always written in full.

The addition of a minus (—) sign to any of the above means "Light". Double minus (— —) means "Very Light". The addition of a plus (+) sign means "Heavy or Severe". The omission of any sign means "Moderate".

Examples: R+: Heavy rain. A—: Light hail. S——: Very light snow.

Obstructions to Vision

F	Fog	D	Dust
GF	Ground fog	BS	Blowing snow
IF	Ice fog	BD	Blowing dust
H	Haze	BN	Blowing sand
K	Smoke		

Sea Level Pressure

Sea Level Pressure is indicated by a group of three figures representing tens, units, and tenths of Millibars. The initial "9" or "10" is omitted.

Examples: "148" means 1014.8 millibars. "899" means 989.9 millibars.

In Canada, Sea Level Pressure varies roughly between 960.0 and 1050.0 millibars.

Temperature

Temperature is indicated by figures representing its value to the nearest degree Celsius. e.g. "9" means 9°C. Below zero temperature is indicated by a minus (—) sign preceding the figure. e.g. "—20" means —20°C. Zero degrees is shown as "0".

Dewpoint

The dewpoint is indicated by figures representing its value to the nearest degree Celsius, e.g. "4" means 4°C. Below zero dewpoint temperature is indicated by a minus (—) sign preceding the figure, e.g. "—15" means —15°C.

Wind

The wind direction is reported in degrees of azimuth (to the nearest 10) e.g. 01 = 010°, 09 = 090°, 28 = 280° etc. The direction is that from which the wind is blowing and it is reported from 36 directions in all. (Note: only the 30° intervals are numbered in Fig. 22)

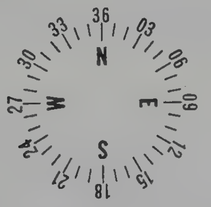


Fig. 22.

Wind direction is in degrees **True** (except when given by a tower for take-off or landing, when it is in degrees **Magnetic).** Wind speed is in **knots.**

Gustiness is indicated by a G after the speed, e.g., 3020G. The speed of the peak gust may be given after the G, e.g., 3020G32. (Wind from 300° 20 kts gusting to 32 kts.) Squalls are indicated by "Q" following the wind speed, e.g., 3025Q. Peak gusts with the squalls may be indicated by the number following Q, e.g., 3025Q35.

A windshift may be reported in the remarks portion as follows: WSHFT 1450Z, meaning "A windshift occurred at 14:50 GMT."

Altimeter Setting

The Altimeter Setting is indicated by a group of three figures representing the pressure in inches and hundredths of inches. The first figure (whether 3 or 2) is omitted, hence 30.00 inches is written 000. 29.72 inches is written 972. (A number beginning with 5 or higher presupposes an initial 2; a number beginning with 4 or lower presupposes an initial 3.)

Clouds

The cloud form or an obscuring phenomenon, corresponding to each layer reported in the sky condition group, is given by an abbreviation followed by a number giving the tenths of sky concealed by the layer.

CI	cirrus	ST	stratus
CS	cirrostratus	SF	stratus fractus
CC	cirrocumulus	SC	stratocumulus
AS	altostratus	CU	cumulus
AC	altocumulus	CF	cumulus fractus
ACC	altocumulus castellans	CU +	heavy cumulus
NS	nimbostratus	CB	cumulonimbus

Runway Visual Range

RVR (Runway Visual Range) is reported from certain selected stations only. The visual range in hundreds of feet follows "VR" in code.

Example: VR32 means "(Runway) Visual Range 3200 feet". R18VR32 means "Runway 18, Visual Range 3200 feet".

Runway Visual Range is not given in Canadian weather reports. This information is available from certain airport control towers on request.)

Pireps

Pilot reports of clouds not visible from the ground are coded with the sky condition symbol followed by the MSL height in hundreds of feet to indicate cloud **tops.** Symbol **preceded** by height indicates cloud **base.**

Example: BKN85 means "Top of broken clouds at 8500 feet".

Remarks

Any additional remarks are shown in teletype symbols and in abbreviations of plain English words, e.g. DRK OVCST NW means "Dark overcast in northwest".

Information about NOTAMS in effect that are applicable to the airport and/or reporting station are given.

Missing Data

Any items which are normally sent, but for some reason are missing from the transmission, are indicated by the letter "M" entered in place of the missing data.

Date and Time

Airway Weather Reports are preceded by six-figure groups and letters indicating the date and time. The first two figures give the day of the month and the next four figures the time (on the 24-hour clock).

Time used on all teletype weather networks in North America is GMT, or "Z" time.

Frequency

Normally, weather teletype sequences are transmitted over a national network by airport weather stations once every hour. "Special" reports may be transmitted at more frequent intervals when the weather is changing rapidly.

AVIATION WEATHER REPORT

Example:

SA 106 12 0900Z

YWG S 3 SCT M7 OVC 1½R-FK 926/5/3/0404/925 VR23 OVC 55 RBO5 OVC V BKN.

SA: Aviation Weather Report

106: Meteorological Teletype Circuit Number

12 0900Z: Date is the 12th day of the month and the time of the report is 900 GMT.

YWG: Code letters of station reporting (YWG means Winnipeg).

S: Type of report (S means Special).

3 SCT: Sky condition (3 means 300 feet. SCT means scattered).

M7 OVC: Ceiling (M means measured. 7 means 700 feet. OVC means overcast).

1½: Visibility (1½ means 1½ miles).

R-FK: Obstructions to vision (R-means light rain. F means fog. K means smoke).

926: Sea level pressure (926 means 992.6 millibars).

5: Temperature (5 means 5°C).

3: Dewpoint (3 means 3°C).

0404: Wind (04 means from 040°, 04 at 4 mph).

925: Altimeter setting (925 means 29.25 inches mercury).

VR23: Runway Visual Range (23 means 2300 feet).

(R25VR23 would signify "Runway 25, Visual Range 2300 ft.")

OVC 55: Pireps (Pilot reports top of overcast at 5500 feet MSL).

RB05 OVC V BKN: Remarks (Rain began 5 minutes past the hour. Overcast variable to broken).

JBI REPORTS

Until recently also included in the Aviation Weather Reports was a report on the runway braking action (James Brake Index). These reports are now transmitted on the same teletype circuit as NOTAMS and are available for the information of pilots as a Voice Advisory from the control tower at controlled airports and from aeradio stations at uncontrolled airports. Because the condition of the runway at his airport of destination is of as much concern to the pilot as is the condition of the weather, it is of importance to know where this information is available. These reports are issued at such times as the JBI reading for any runway falls to .6 or below. As conditions change, new JBI reports are issued. When the JBI reading exceeds .6, a cancelling message is transmitted. When the JBI reading falls below .3, the readings are passed immediately to ATC for relay to inbound flights.

Such a report of runway conditions might appear as follows:

JBI YOW RWY 07/25 — 2 .28 1200.

In this case, the report concerns Runway 07/25 at Ottawa International. The temperature is —2°C at 1200 GMT.

The readings are taken by a James Brake Indicator (JBI) on a scale from 0 (non-existant braking) to 1 (excellent braking). The braking action on the runway is rated at an average of .28 for the full length of the runway.

JBI readings are taken when there is dry snow, ice or frost on runways, when temperature is close to the freezing range, when there is measurable precipitation and when snow removal and sanding operations have been undertaken. JBI readouts are not usable in conditions of slush or wet snow.

Therefore, when the solid contaminant, such as ice or snow, changes to a liquid form, such as water or slush, because of a temperature rise, the JBI report is replaced with a description of the runway condition and is referred to as a Runway Surface Condition (RSC). Such a report might appear as follows:

JBI YOW N/A RSC 07/25 wet with .25/.75 slush centre third.

Decoded, this report reads: The JBI report for Ottawa, Runway 07 is cancelled. Runway Surface Condition report is issued instead. Runway 07/25 is wet with slush on the centre section varying from a depth of ¼ inch to ¾ inch.

RADAR WEATHER REPORTS

Specially designated weather radars are used at principal weather offices to observe precipitation patterns. Reports are broadcast when available by aviation radio stations.

Example:

DTW★ RADAR 08:45 EST (13:45Z) SCATTERED AREA OF SHOWERS AND THUNDERSTORMS DECREASING IN INTENSITY EXTENDING FROM 20 MILES NORTHEAST OF BATTLECREEK TO 20 MILES SOUTH OF SOUTH BEND . . . 45 MILES WIDE . . . MOVING EAST AT 15 KTS . . TOPS 20,000 . . A THUNDERSTORM 4 MILES DIAMETER WITH TOPS 25,000 IS CENTERED 20 MILES NORTH OF FLINT.

★ **Detroit**

WINDS ALOFT REPORT

Weather Stations report the upper winds four times daily. The reports cover the wind speed and direction at thousand-foot levels up to 10,000'; from 10,000' to 20,000', at two thousand-foot levels; and above 20,000' at five thousand-foot levels. Heights are Above Mean Sea Level.

Example:

YWG 15Z 01309 20812 0515 43616 3421

Decoded, the above reads:

YWG: Winnipeg

15Z: 15:00 GMT (Greenwich Mean Time).

01309: Surface wind from 130° at 9 kts.

20812: 2000 ft. Wind from 080° at 12 kts.

★0515: 3000 ft. Wind from 050° at 15 kts.

43616: 4000 ft. Wind from 360° at 16 kts.

★3421: 5000 ft. Wind from 340° at 21 kts.

★*At odd altitudes, the altitude figure is omitted.*

WEATHER FORECASTS

A **Weather Forecast** is a statement of **anticipated** conditions expected at a particular place, over an area, or along a route during a given period, based on available information. The forecaster will usually state the degree of confidence with which the forecast is made.

In planning a flight, the pilot must have reasonable knowledge of the following facts:

1. Whether the ceiling and visibility at his terminal—or at alternate landing places—will be sufficiently good to make a safe landing. If the flight is to be made by visual contact, the ceilings and visibilities must be "VFR" along the entire route.
2. He must know the wind conditions at various flight levels to estimate the time and fuel required, and to choose a route and altitude to fly that will give him the most favorable winds.
3. He must know at what levels to expect icing conditions and how to avoid severe icing zones.
4. He must know where thunderstorms, turbulence or hail may be encountered, so that he may delay the start of his flight or land en route to avoid dangerous weather in the air.

Since the weather is constantly changing, the conditions shown in a Weather Report may change during a flight and a **forecast** of the changes must be obtained before departure.

The following code identifies the various types of forecasts:

FT — Terminal Forecast

FA — Area Forecast

FD — Upper Winds and Temperature Forecast

FL — Sigmet Message

AREA FORECAST (FA)

An Area Forecast is a general statement of weather conditions to be expected over a particular region. They are prepared every 6 hours and are valid for a 12 hour period. The Area Forecast includes **Regional Forecasts** for each Region in the Area.

Example:

FA YEG 1 171720Z
18-06Z
ALL HTS ASL UNLESS NOTED
PROG
FLAT RDG FORT SMITH-MCMURRAY-LETHBRIDGE AT 1800Z MOVG TO MEDICINE HAT-NORTH BATTLEFORD 250 MI E OF FORT SMITH BY 0600. SLOLY DPNG TROF PRINCE GEORGE-FORT NELSON. AIR UNSTBL AND FAIRLY MOIST. UPSLP CLDS OVR SRN ALTA.
YEG-1
LETHBRIDGE RGN
CLDS AND WX. 50 OVC 80 110 BKN 140 BCMG 50 BKN 80 110 BKN 140 AFT 04Z. ICG. LGT RIME ICGIC.
FRLVL 40
YEG-2-3-4
CALGARY CORONATION EDSON REGIONS
CLDS AND WX. 60 BKN CU100 /-SCT BCMG /-SCT AFT 01Z. ICG. LGT RIME ICG IN CU. FRLVL 40
YEG-5
EDMONTON RGN
CLDS AND WX. 60 BKN CU100 OCNLY 60 BKN CU + 150 6RW- BCMG 100 BKN 130 BY 0200Z. ICG. MDT CLR ICG IN CU + 60-150 OTRW LGT ICGIC.
FRLVL 40
TURBC MDT VCNTY CU + TIL 2400Z

Decoded, the above reads:

Area forecast (FA) issued by the weather office at Edmonton International at 1720 GMT on the 17th day of the month and valid from 1800 GMT to 600 GMT on the 18th.

All heights above Mean Sea Level unless noted.

Prognosis: Flat ridge overlying Fort Smith, McMurray and Lethbridge at 1800 GMT is moving towards Medicine Hat and North Battleford. Will be 250 miles east of Fort Smith by 600 GMT. Slowly deepening trough Prince George to Fort Nelson. Air unstable and fairly moist. Upslope clouds over Southern Alberta.

YEG 1: Lethbridge Region

Clouds and Weather: 5000 feet overcast, tops at 8000' and 11000' broken with tops at 14000'. Becoming 5000' broken, tops at 8000' and 11000' broken, tops at 14000' after 400 GMT.

Icing: Light rime icing. Freezing level 4000'.

YEG 2-3-4: Calgary, Coronation, Edson Regions.

Clouds and Weather: 6000' broken. Cumulus clouds with tops at 10000'. High thin scattered cirrus. Becoming high, thin scattered cirrus after 100 GMT.

Icing: Light rime icing in cumulus clouds. Freezing level 4000'.

YEG 5: Edmonton Region.

Clouds and Weather: 6000' broken. Cumulus clouds with tops at 10000'. Occasionally 6000' broken. Heavy cumulus clouds with tops at 15000'. Visibility 6 miles in light rain showers. Becoming 10000' broken, tops at 13000' by 200 GMT.

Icing: Moderate clear icing in heavy cumulus from 6000' to 15000'. Otherwise light icing in cloud. Freezing level 4000'.

Moderate turbulence in vicinity of heavy cumulus cloud until 2400 GMT.

TERMINAL FORECAST (FT)

A Terminal Forecast states in specific terms the ceiling, cloud heights in hundreds of feet above the station, cloud layers in ascending order of height, visibility in s.miles (omitted if over 8 miles) and surface wind (omitted if less than 10 kts). Terminal Forecasts are transmitted 4 times daily. Twelve hour Terminal Forecasts are designated by the letters FT1 and 24 hour Forecasts by the letters FT2. The validity period is indicated in the forecast.

Example:

FT1 YYC 241645Z
17-05Z
YYC 30 SCT C90 OVC 1412. 1400Z C20 OVC 6RW-1415. 1900Z C30 BKN 1415.

Decoded, the above reads:

A 12 hour Terminal Forecast issued by the Calgary Weather Office at 1645 GMT on the 24th day of the month and valid from 1700 GMT to 0500 GMT.

Terminal forecast for Calgary.

30 SCT C90 OVC 1412: 3000 feet, scattered clouds, ceiling 9000 feet, overcast, surface wind from 140° at 12 kts.

1400Z C20 OVC 6RW- 1415: By 14:00 GMT becoming ceiling 2000 feet, overcast, visibility 6 miles, light rain showers, surface wind from 140° at 15 kts.

1900 Z C30 BKN 1415: By 19:00 GMT becoming ceiling 3000 feet, broken clouds, surface wind from 140° at 15 kts.

Example:

FT2 YYZ 091630Z
17-17Z
YTR 30 SCT C100 BKN / OVC 6H 2315G20 OCNL RW- 10Z 50 SCT C120 BKN 2315.

Decoded, the above reads:

A 24 hour Terminal Forecast issued by the Toronto weather office at 1630 GMT on the 9th day of the month, valid from 1700 GMT on the 9th to 1700 GMT on the 10th.

Terminal forecast for Trenton. 3000 feet scattered, ceiling 10,000 feet broken. High cirrus overcast. Visibility 6 miles in haze. Surface winds from 230° at 15 kts gusting to 20 kts. Occasional light rain showers. At 1000 GMT 5000 feet scattered, ceiling 12,000 feet broken. Surface winds from 230° at 15 kts.

UPPER WINDS AND TEMPERATURE FORECASTS (FD)

An Upper Winds And Temperature Forecast provides an estimate of upper wind conditions and temperatures at selected levels. They are transmitted every six hours and are valid for the period indicated on the forecast itself.

Example:

FD1 WAO 171520
BASED ON 1200 DATA VALID 171800 FOR USE 15-21

	3000	6000	9000	12000	18000
YVR	1227	1315-09	1007-11	9900-16	3028-26
YYF	1223	1411-13	9900-14	3310-9	3132-30
YXC		9900-17	3407-18	3317-26	3239-33
YYC		3212-19	3316-20	3324-26	3240-38

Decoded, the above reads:

Winds and temperature forecast, issued by the Montreal Meteorological Centre at 1520 GMT on the 17th day of the month.

Based on data fed into the computer at 1200 GMT. Forecast is valid for 1800 GMT on the 17th day of the month and for use for 3 hours either side of 1800 GMT, i.e. from 1500 to 2100 GMT.

Vancouver: At 3000 feet, wind from 120° at 27 knots.

At 6000 feet, wind from 130° at 15 knots. Temperature —9°C.

At 9000 feet, wind from 100° at 7 knots. Temperature —11°C.

At 12,000 feet, winds are light and variable (9900 code). Temperature —16°C.

At 18,000 feet, wind from 300° at 28 knots. Temperature —26 °C.

Interpolation: Winds aloft are given for a number of representative levels. Winds at heights not reported can be obtained by interpolation. e.g.:

Question: What is the wind at Penticton (YYF) at 4500 feet?

Answer: The wind at 3000' is from 120° at 23 knots.
The wind at 6000' is from 140° at 11 knots.

Hence, the wind is veering approximately 10° per 1500 feet. At 4500 feet it would therefore be from approximately 130°.

The velocity is decreasing 6 knots per 1500 feet. At 4500 feet, it would therefore be blowing at approximately 17 knots.

The same kind of interpolation can be made for the temperature.

"WEATHER SENSE"

The pilot gets his picture of the current weather along his intended route from the forecast, a study of the weather map, teletype and radio reports, and from what he sees. At times, when no forecaster is available, he must make his own analysis from available data.

The surface weather map represents a broad picture of weather conditions at the time of observation over a large geographical area. This is its principal value to the pilot.

It is always advisable to look at a weather map, not from the standpoint of an observer, but with a view to looking for the weather, wind circulation, ceilings and visibilities along the route and to either side of the route to be flown. The pilot should know which way to turn in case the weather "closes in" at his terminal. Always have an "out" in case the forecast fails to materialize.

If radio is carried, keep a constant check on the weather reports which are broadcast regularly by aeradio stations. If at any time in doubt, call an aeradio station and ask for the weather ahead. *"Keep in touch with the weather to be weatherwise".*

WEATHER INFORMATION SOURCES

PRE FLIGHT

For forecasts and weather information in Canada, contact the Aviation Forecaster, or Briefer, at the airport or the Public Weather Office in your town. In the U.S., contact the Flight Service Station Forecaster at the airport or the Weather Bureau Office in the town.

Briefing. At Aviation Forecast Offices trained weather experts will discuss your proposed flight and will review with you the latest weather maps, aviation weather reports, area and terminal forecasts, radar precipitation patterns, sigmets, advisories to light aircraft, Pireps, etc. If you are not familiar with the format of the coded reports, they will explain them to you in plain language and will advise you as regards the existing and anticipated weather conditions along your route.

IN FLIGHT

You can request weather information in flight from any DOT or FAA Communications Station by radio. All aeradio stations (L/MF, OMNI, VORTAC, etc) in Canada having voice facilities broadcast the weather at 17 and 47, or 20 and 50 minutes past the hour. (The weather broadcast times for all aeradio stations are published in Air Navigation Radio Aids.) In the U.S., Flight Service Stations broadcast weather information at 15 minutes past the hour. In addition, special weather reports are broadcast off-schedule immediately when available. You should avoid calling for weather information during these periods in order to avoid interrupting the broadcast. If your need is urgent, however, you may request the announcer to delay the regular scheduled broadcast to provide the information you need.

In air-ground communications when transmitting meteorological information to arriving aircraft, the term CAVOK (kav-oh-kay) is used to indicate the weather condition in which there is no cloud of any amount below 5000 feet, 6 miles or more visibility and no precipitation or thunderstorm activity. The term is also used in ATIS messages.

Communications with DOT operated aeradio stations should be conducted on the appropriate VHF or HF frequency (the VHF frequencies of 122.2 or 126.7 or the HF 5680). The aeradio station has the facility to reply on the Non Directional Beacon frequency or on the VOR frequency or on any of the discreet frequencies such as 126.7. The pilot should specify what frequency he is monitoring when calling for weather information from aeradio stations.

Transcribed Weather Broadcasts. Many aeradio stations in Canada and Flight Service Stations in the U.S. continuously broadcast tape recorded weather information on the station's primary low frequency navaid (200 to 415 KHz). The broadcast includes weather reports, flight precautions, significant enroute weather, terminal forecasts, radar reports, Pireps, NOTAMS, SIGMETS, advisories and winds aloft data.

SIGMETS (Significant Met. advisories) are radio weather broadcasts to aircraft in flight warning of severe and hazardous weather conditions. These would include severe turbulence, severe icing, thunderstorms, squall lines, hurricanes, heavy hail, etc. They are broadcast immediately upon receipt on navigational aids voice channels; they are included in the twice hourly scheduled broadcasts for the duration of the period for which they are valid; they are transmitted directly to specific aircraft when such action is considered appropriate by the aeradio station operator; and they are issued on request to aircrews over normal air-ground communications channels.

Advisories to Light Aircraft are warnings of weather conditions less severe than SIGMETS, but potentially hazardous for light aircraft.

Both are broadcast over normal en route voice channels, in the areas affected, immediately the condition is known (to specific individual aircraft when considered advisable) and at regular intervals thereafter. Stay tuned to en route airway communication channels at all times for unexpected weather developments. Consult DOT Circulars (Can), Flight Information Manual and Airman's Guide (US) for the latest procedures.

PIREPS are reports by pilots in flight to airway stations en route of any unusual weather conditions encountered (such as unpredicted thunderstorms, tornadoes, hail, severe icing, mountain waves, low ceilings or visibility, dust and sand storms, etc.) They should be reported to the nearest aeradio station over normal en route navaid voice frequencies and will be broadcast immediately by the station receiving them. They will also be included in the subsequent half-hourly airway weather broadcasts.

Air Navigation . . .

The Earth on which we live is a ball, or sphere, technically on oblate spheroid. Not knowing any better, the human race has for centuries lived on the outside of the sphere — enduring heat and cold, clouds and rain, snow and sleet, fog, mist and mortal uncertainty. In due course, cities of the future will be located underground in a world of perfectly regulated heat, light and air conditions.

Meanwhile, we are here today and gone tomorrow, and must make the best of our cabbage-patch world, such as it is. Man is a restless soul, and travel and curiosity have always been two of his most cultivated and persevering habits. To make it possible to move about on this great Terrestrial Sphere then, he must have some master plan to enable him to define position, direction and distance.

LATITUDE AND LONGITUDE

As a well-planned modern city is an orderly gridwork of intersecting streets and avenues, so ancient Master Minds have divided the surface of our sphere into a geometrical pattern of intersecting circles called the **Graticule.** Those running north and south are **Meridians of Longitude.** Those running east and west are **Parallels of Latitude.** In exactly the same way that Wun Wing Lo's Cafe may be located at the corner of 49th Street and 11th Avenue, so the Town of Riverton may be located at the intersection of the 75th Meridian West and the 40th Parallel North.

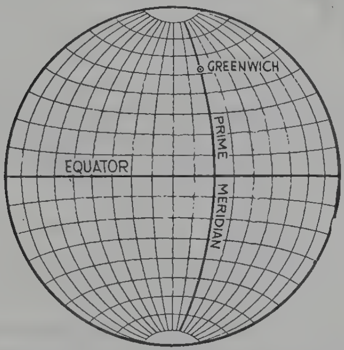


Fig. 1. Latitude and Longitude.

Meridians of Longitude are semi great circles joining the True or Geographic Poles of the Earth. They are also called True Meridians since they join the Geographic Poles, as opposed to Magnetic Meridians which join the Magnetic Poles.

Longitude is measured from 0° to 180° east and west of the **Prime Meridian** which is the Meridian which passes through Greenwich, England. The Prime Meridian is numbered 0°. The Meridian on the opposite side of the Earth to the Prime Meridian is the 180th and is called the **International Date Line** for here the time changes a day.

Longitude is measured in degrees (°), minutes (') and seconds (''). There are 60 minutes in a degree and 60 seconds in a minute.

Parallels of Latitude are circles on the Earth's surface whose planes lie parallel to the Equator. The **Equator** is a great circle on the surface of the Earth lying equidistant from the Poles.

Latitude is measured from 0° to 90° north or south of the Equator, which is numbered 0°. Latitude is expressed in degrees, minutes and seconds.

GEOGRAPHICAL CO-ORDINATES

The location of cities, towns, airports etc. may be designated by their geographical co-ordinates, that is, the intersection of the lines of latitude and longitude marking their position on a map.

In Fig. 2, the co-ordinates of the airport at Matagami are 49°46'N, 77°48'W. In other words, the airport is located 49 degrees, 46 minutes north of the Equator and 77 degrees 48 minutes west of the Prime Meridian.

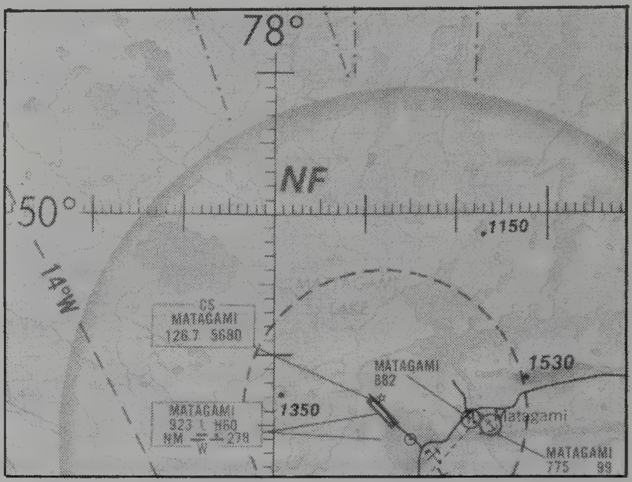


Fig. 2. Geographical Co-Ordinates.

On a chart, the lines representing the Meridians and Parallels are numbered (in Fig. 2, 78°W and 50°N). Each small mark along the lines represents one minute.

One position on the Earth's surface is related to another by the **Change of Latitude** (written Ch.Lat.) and the **Change of Longitude** (Ch.Long.) between two places.

If an airplane is to proceed from a place, say, Dunnville, to a place, Harrisburg, the Ch. Lat. is named north or south according to whether Harrisburg is north or south of Dunnville. Similarly, the Ch. Long. is named east or west, depending on whether Harrisburg is east or west of Dunnville.

Example:

Harrisburg.	Lat.	60°27'N.	Long.	40°20'W.
Dunnville.	Lat.	45°30'N.	Long.	15°30'E.
	Ch. Lat.	14°57'N.	Ch. Long.	55°50'W.

In the above example, Harrisburg is obviously north of Dunnville 14°57' of latitude, hence its Ch. Lat. is 14°57'N. Harrisburg is west of Dunnville, but as Dunnville is east of the Prime Meridian, the Ch.Long. in this case is the sum of the longitude of the two places. Not that any community 15° east of the Prime Meridian is likely to have a name such as Dunnville, but the example is merely chosen to help you to get the general idea.

TIME AND LONGITUDE

The Earth rotates about its own axis. It also revolves in an elliptical orbit around the Sun. As a result of these revolutions of the Earth, it appears to us as though the Sun were revolving around the Earth instead.

The time between one apparent passage, or transit, of the sun over a Meridian and the next passage over that same Meridian is called an **Apparent Solar Day** and varies throughout the year.

To provide a convenient method of measuring time, an imaginary Sun, called the Mean Sun, is assumed to travel at a uniform rate of speed throughout the year. The interval between two successive transits of the Mean Sun is called a **Mean Solar Day.**

The Mean Solar Day is divided into 24 equal hours. The Mean Sun is assumed to travel once around the Earth every Mean Solar Day, and therefore travels through an angle of 360° of longitude in that time. Hence, **Mean Time** may be expressed in terms of longitude, and vice versa.

For Example:

24 hrs. =	360° Long.	360° Long. =	24 hrs.
1 hr. =	15° Long.	1° Long. =	4 min.
1 min. =	15' Long.	1' Long. =	4 sec.
1 sec. =	15'' Long.	1'' Long. =	1/15 sec.

Time will vary on different Meridians on the Earth at any particular instant from 0 hours to 24 hours. The Mean Time on any particular Meridian is called its **Local Mean Time (LMT).**

In order to have a universal standard time for reference at any point on the Earth, the Local Mean Time for the Greenwich Meridian is internationally accepted. This is called **Greenwich Mean Time (GMT)** and is also referred to as "Z" Time.

The LMT of any place **east** of Greenwich is **ahead of** GMT. e.g.: Cairo 14:00 = Greenwich 12:00.

The LMT of any place **west** of Greenwich is **behind** GMT. e.g.: Greenwich 12:00 = Toronto 07:00.

If every place kept its own Local Mean Time, confusion would result. For this reason the world is divided in 24 Time Zones. (Fig. 3). Each Zone is 15° of longitude wide and keeps the time of the *mid Meridian* of the Zone. The Zones are numbered from 1 to 12 east of Greenwich (minus) and 1 to 12 west of Greenwich (plus). If either the Zone number or the longitude of the mid Meridian of the Zone is known, **Zone Time** can readily be converted to GMT (Fig.3). It will be seen that when it is noon at Greenwich it is midnight on the 180th Meridian. Here the time changes a day. Travelling from east longitude to west longitude (i.e. from Tokyo to San Francisco), the time goes back a day (i.e. from Wednesday to Tuesday). Travelling from west longitude to east longitude (i.e. from San Francisco to Tokyo), time goes forward a day (i.e. from Tuesday to Wednesday).

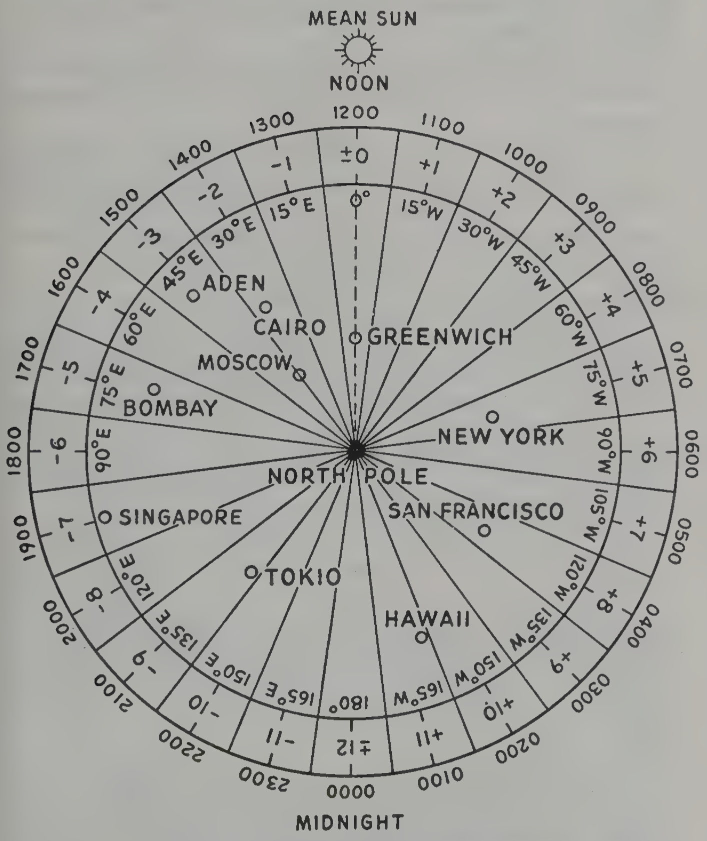


Fig. 3. Zone Time and Longitude.

Air Traffic Control and Meteorological facilities in both Canada and United States operate on GMT, or "Z" Time — not local Zone Time. A pilot flying on a long cross country flight would be wise to adjust his personal wrist watch (or the airplane clock) to GMT and refer to it when radioing position reports. Such a precaution will eliminate chance of error in reporting time as it is often most difficult to determine exactly when one zone (which, to add to the confusion, might be on local daylight saving time) ends and another begins. To be one hour in error when reporting to an Air Traffic Control unit could have serious consequences.

When travelling westward into a new time zone, watches are turned back one hour from the previous zone. When travelling eastward, watches are advanced one hour each time a new time zone is reached.

The relationship of GMT to Standard Zone Time in North America is indicated in the following example:

12:00 (noon)GMT — Greenwich Mean Time
= 8:30 NST — Newfoundland Standard Time.
(GMT is NST + 3-1/2 hrs.)
= 08:00 AST — Atlantic Standard Time.
(GMT is AST + 4 hrs.)
= 07:00 EST — Eastern Standard Time.
(GMT is EST + 5 hrs.)
= 06:00 CST — Central Standard Time.
(GMT is CST + 6 hrs.)
= 05:00 MST — Mountain Standard Time.
(GMT is MST + 7 hrs.)
= 04:00 PST — Pacific Standard Time.
(GMT is PST + 8 hrs.)

Note: the above abbreviations are frequently contracted to "Z" (Greenwich Mean Time), "A" (Atlantic Standard Time), "E" (Eastern Standard Time), etc.

GREAT CIRCLES AND RHUMB LINES

A **Great Circle** is a circle on the surface of a sphere whose plane passes through the centre of the sphere. (Fig.4). The shortest distance between any two points (A and B in Fig. 4) on the surface of a sphere is the shorter arc of the Great Circle joining the points.

The Equator is a Great Circle. The Meridians are only Semi Great Circles since they do not completely encircle the Earth but run only half way around it from Pole to Pole.

Since a Great Circle Route represents the **shortest distance** between two points on the surface of the Earth, its advantage to the air navigator will be obvious. Most long-distance flights are flown over Great Circle Routes or modified Great Circle Routes.

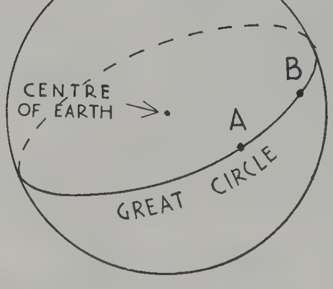


Fig. 4. Great Circle.

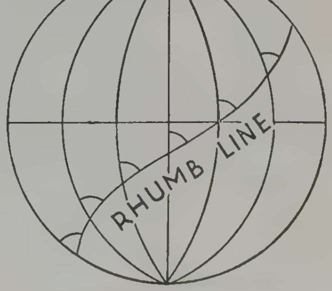


Fig. 5. Rhumb Line.

A Great Circle, however, does not cross the Meridians it meets at the same angle. For this reason, the heading must be changed at frequent intervals to enable the airplane to maintain a Great Circle Route.

A **Rhumb Line** is a curved line on the surface of the Earth, cutting all the Meridians it meets at the same angle. (Fig. 5.) A Rhumb Line Route offers to the navigator, therefore, the advantage of following a constant heading.

HEADINGS AND BEARINGS

Direction is measured in degrees clockwise from North which is 0° (or 360°). East is 90°. South is 180° and West is 270°.

The direction of any point on the surface of the Earth from an observer is known, if the angle at the observer between a Meridian passing through the observer and a Great Circle joining him to the object is known. This angle is the **Azimuth** or the **Bearing** of the point. The angle is measured clockwise from the Meridian through 360° (Fig.7.).

The angle between the Meridian over which an airplane is flying and the line representing the direction in which the airplane's "nose" is pointing (the fore and aft axis), measured clockwise, is the airplane's **True Heading** (Fig.6.).

Since the Meridians are **imaginary lines**, the angle between a Meridian and a particular Heading or Bearing cannot be measured directly. By the aid of a compass, however, the direction of the Meridian may be determined, and the angle ascertained.

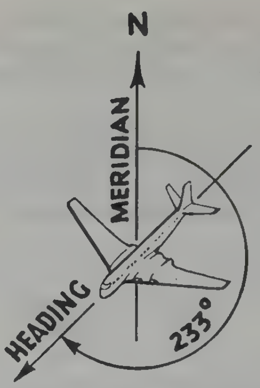


Fig. 6. Heading (233°).

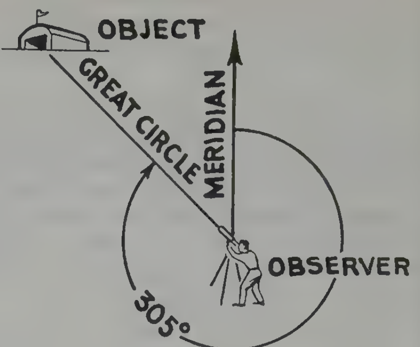


Fig. 7. Bearing (305°).

THE EARTH'S MAGNETISM

The Earth is a magnet and like any other magnet has a North and South Magnetic Pole. The Lines of Force of the Earth's Magnetic Field are considered to flow from the South Magnetic Pole towards the North Magnetic Pole. A compass needle will be influenced by the Earth's Magnetic Field and will lie parallel to one of the Magnetic Lines of Force with its north seeking Pole pointing to Magnetic North. (This does not necessarily mean that it is pointing directly towards the Magnetic North Pole).

The Magnetic Line in which the Compass Needle lies is called a **Magnetic Meridian.**

Now refer to Fig. 8. Note that the Earth's Magnetic Lines of Force are *horizontal* at the Equator, but become gradually *vertical* towards the Poles. This means that there are two forces acting on a compass needle. One, the horizontal "H" force, acting horizontally, tends to hold the needle level (B). The other, the vertical "Z" force, acting vertically, tends to pull the seeking end of the needle down (A and C). A freely suspended magnet under the influence of a large directional (H) force and a small vertical (Z) force would lie parallel to the Earth's surface. This occurs near the Magnetic Equator. If the magnet were moved north or south from the Equator, H force would lessen and Z force would increase and the pole seeking end of the magnet would be pulled down from the horizontal. The angle between the horizontal and the plane the magnet lies in under the influence of Z force is called **Dip** and from latitudes north or south of 45 degrees is quite large, increasing to near 90 degrees at the Poles. Dip must be corrected or compensated for in a compass during construction.

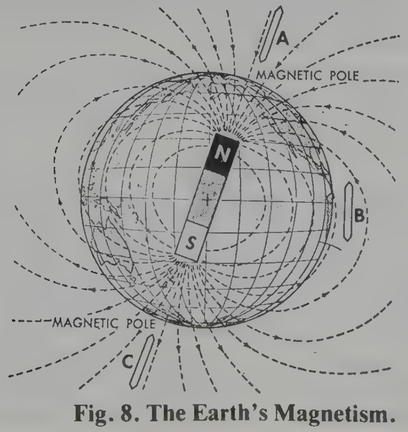


Fig. 8. The Earth's Magnetism.

VARIATION

The Magnetic Meridians do not coincide with the True Meridians because the North Magnetic Pole does not coincide with the True, or Geographic, Pole. In fact, the North Magnetic Pole rotates around the True North Pole in a circle, in a direction E to W, completing the circuit once in every 960 years. At this time in the Earth's history, the North Magnetic Pole is located near Bathurst Island in the Canadian Arctic, about 1000 miles south of the True North Pole.

The angle between the True Meridian and the Magnetic Meridian in which the compass needle lies, is called **Magnetic Variation.**

Since the Magnetic North Pole is not stationary, but moving in a circle, obviously the variation is not constant at any one place, but changes slowly from year to year. This is called **Annual Change** and must be taken into consideration when taking the variation for any particular locality from old maps.

ISOGONIC LINES

The direction of the Earth's Magnetic Field is measured, periodically, over most of the Earth's surface. The results of such a survey are plotted on a chart. Lines are drawn on the chart joining places having the same variation and these lines are called **Isogonic Lines** or **Isogonals.** Isogonals are not straight lines but bend and twist due to the influence on the magnetic field of local magnetic bodies below the Earth's surface.

The isogonals are numbered east and west according to whether the compass variation is to the east or west of True North.

Isogonic lines are represented on aeronautical charts by dashed lines with the amount of variation indicated. In Fig. 2, the 14° W isogonic line can be seen to pass near the Matagami Airport.

AGONIC LINES

In each Hemisphere there will be places where the North Pole and North Magnetic Pole will be in transit, that is, where they will lie in the same straight line. These places will, therefore, have no magnetic variation. Lines drawn through places of "no variation" are called **Agonic Lines.** Like the isogonic lines they twist and curve, due to the local attraction of magnetic bodies in the Earth.

The agonic line for the Western Hemisphere passes approximately through Thunder Bay, Ontario, and a little east of Chicago, Illinois. **East** of this line the variation is **Westerly** and **West** of it the variation is **Easterly.**

THE EFFECT OF VARIATION

It can, therefore, be seen that if the Magnetic Pole lies west of the True Pole from a given point, the compass needle will point **west** of True North. Hence, the Magnetic Meridian will lie **west** of the True Meridian.

In this case the **variation** is named **west.** (Fig. 9.)

Similarly, if the compass needle points **east** of True North, the Magnetic Meridian will lie **east** of the True Meridian, and the **variation** will be named **east.**

Figures 10, 11, and 12 are intended to represent a compass installed in an airplane whose nose is pointed towards True North.

The Lubber Line of a Compass is always permanently fixed in the fore and aft line of the airplane and therefore always indicates the direction in which the airplane is heading. The compass card is always read against the Lubber Line.

The compass needle pivots and is free to point always towards Magnetic North, regardless of what direction the airplane may be heading.

In Fig. 10, there is no variation. The Magnetic Meridian, in which the compass needle lies, coincides with the True Meridian in which the longitudinal axis of the airplane lies.

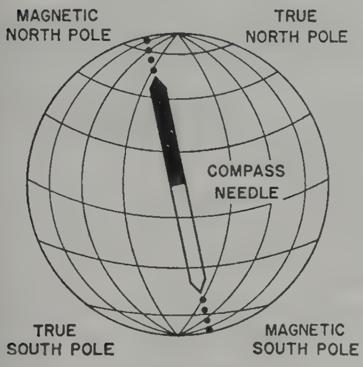


Fig. 9. Variation (West).

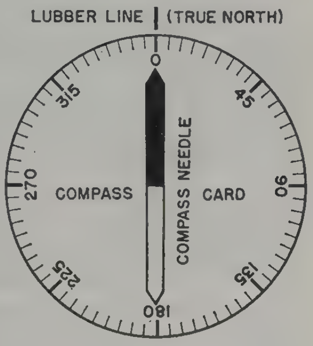


Fig. 10. No Variation.

Fig. 11 illustrates Westerly Variation. The compass needle is deflected 30° west of the True Meridian. The compass card is always attached to the compass needle and, therefore, when the compass needle is deflected towards the West, it drags the whole compass card around with it. As a result, the reading at the Lubber Line is more than it should be. Although the airplane is actually pointed towards True North, the compass reads 30°.

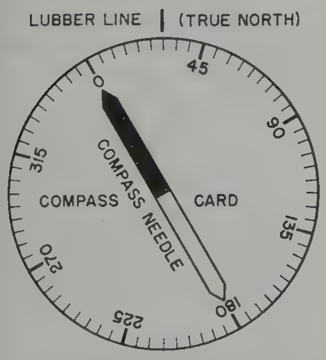


Fig. 11. Variation 30° West.

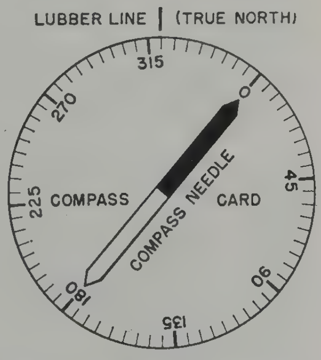


Fig. 12. Variation 40° East.

Fig. 12 illustrates Easterly Variation. When the needle is deflected east of the True Meridian, the compass card is rotated so that a smaller reading is opposite the Lubber Line. Although the airplane is in fact pointed towards True North, the compass reads 320°.

Conversion of True and Magnetic Headings

It is necessary for a pilot to be able to convert True Headings and Bearings to Magnetic Headings and Bearings, and vice versa, rapidly in the air.

To convert Magnetic to True:
Subtract Westerly Variation
Add Easterly Variation
To convert True to Magnetic:
Add Westerly Variation
Subtract Easterly Variation

An easy way to remember how to apply variation is to remember the rhyme:

Variation West, Magnetic Best (Better than True)
Variation East, Magnetic Least (Less than True)

Problem 1. To convert a Magnetic Bearing of 80° to a True Bearing when the Variation is 13°W.

Magnetic Bearing	80°
Variation	13°W
Hence, True Bearing	67°

Problem 2. To convert a True Heading of 136° to a Magnetic Heading when the Variation is 8°E.

True Heading	136°
Variation	8°E
Hence, Magnetic Heading	128°

THE MAGNETIC COMPASS

In some general aviation airplanes, the magnetic compass is the only direction finding instrument installed in the airplane. Even in airplanes that have more complicated direction finding devices, such as the directional gyro, these instruments must be set with reference to the magnetic compass.

A compass is a reliable, self contained instrument that requires no external power source. It will continue to perform satisfactorily in a steady climb or glide, provided that neither exceeds more than 20°. In turns or rapid changes of speed, however, the compass will not give an accurate direction reading. To use the instrument properly, a pilot must understand how a compass works and to what errors it is subject.

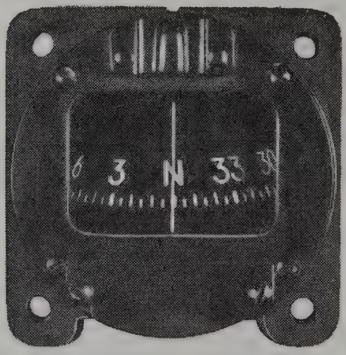


Fig. 13. Magnetic Compass.

CONSTRUCTION OF THE MAGNETIC COMPASS

The Magnetic Compass consists of north seeking magnets (usually two) attached to a float to which is also attached a **Compass Card.** This complete magnet system is mounted on a pivot and is free to rotate. The whole assembly is mounted within the **Compass Bowl.**

To damp out oscillations of the magnetic system which may be caused by turbulence, the bowl is filled with alcohol, or white kerosene. This liquid also helps to reduce the weight of the compass card and the magnets that is carried by the pivot. The liquid also helps to lubricate the pivot point. An expansion chamber is provided to allow for expansion of the liquid due to temperature changes. The bowl and container are of brass, which is non-magnetic.

The Compass Card is usually graduated in 5° divisions (the Compass Headings). The last "0" is omitted from the numbers, which are shown as "3" for "30", "33" for "330", etc. The card is read through a window on which is painted a white vertical line called the "Lubber Line".

The **Lubber Line** indicates the direction the airplane is headed and should be exactly in line with, or parallel to, the fore and aft (longitudinal) axis of the airplane.

Since the headings are painted on the reciprocal side of the card, which the pilot sees looking forward, the card appears to swing the wrong way when the airplane is turning.

COMPASS ERRORS

Deviation

When magnets mounted in simple Direct Reading Compasses are installed in airplanes, they usually do not point directly in the direction of Magnetic North, but, due to the influence of magnetic fields associated with the metal in the airplane's frame and engine, are deflected slightly to what is called **Compass North.**

The angle through which the compass needle is deflected from the Magnetic Meridian is called **Deviation.**

Deviation is named east if the north seeking end of the needle is deflected to the **east** of Magnetic North. It is named west if the needle is deflected **west** of Magnetic North.

If deviation causes the compass needle to be deflected **west** of the Magnetic Meridian, the Compass Card will be dragged around anti-clockwise, and the reading opposite the Lubber Line will be **more** than it should be.

Similarly, if the compass needle is pulled over **east** of the Magnetic Meridian, the Compass Card will be rotated clockwise, and the reading opposite the Lubber Line will be **less** than it should be.

To convert Compass to Magnetic:

Subtract Westerly Deviation
Add Easterly Deviation

To convert Magnetic to Compass:

Add Westerly Deviation
Subtract Easterly Deviation

An easy way to remember how to apply deviation is to remember the rhyme:

Deviation West, Compass Best (Better than Magnetic)
Deviation East, Compass Least (Less than Magnetic)

Problem 1. To convert a Magnetic Heading of 270° to a Compass Heading when the Deviation is 3° East.

Magnetic Heading .... 270°
Deviation.......................... 3° East

Compass Heading .... 267°

Problem 2. To convert a Compass Heading of 002° to a Magnetic Heading when the Deviation is 4° West.

Compass Heading .... 002°
Deviation.......................... 4° West

Magnetic Heading .... 358°

Because a compass can be affected by anything metal, it is essential that pilots avoid placing metallic objects near the compass during flight.

Correction for Deviation by Swinging the Compass: The effect of deviation is neutralized in airplanes as far as possible by a procedure called "Swinging the Compass". The compass is fitted with corrector magnets, which are permanently installed and connected by gears. They arlocated in the top and bottom of the compass case and are adjusted by screws. As the compass is "swung", the screws are adjusted to eliminate deviation. It is rarely possible, however, to completely eliminate it. The deviation remaining after the compass has been "swung" is tabulated on a **Compass Deviation Card** to enable the pilot to make allowance for it. A typical Compass Deviation Card is illustrated in Fig. 14.

The compass is swung on a compass swinging base located remote from any magnetic influences, such as metal hangars, gas pumps, etc. There should be no metal objects in the vicinity of the compass or on the person performing the swing. Magnetic bearings, every 30°, are laid out on the base. The compass is lined up and its compass heading compared with each in turn. The method of correcting deviation is detailed below. The compass should be swung with the **engine running** and **all radio and electrical equipment** functioning. If no compass swinging base is available (at a seaplane base for instance) the airplane can be lined up on the various magnetic bearings required through the sights of a bearing compass.

The simplest method of swinging the compass is as follows:

1. Place airplane on N. Take out Deviation.
2. Place airplane on E. Take out Deviation.
3. Place airplane on S. Take out **half** the Deviation.
4. Place airplane on W. Take out **half** the Deviation.
5. Commencing with the corrected reading on W., place airplane successively on Magnetic Headings every 30° — that is, W., 300°, 330°, N., 030°, 060°, E., 120°, 150°, S., 210°, 240°. Take compass readings on all 12 points. Enter readings on Deviation Card (Fig.14) which is then placed near the compass in the airplane. Enter details in the Aircraft Log.

FOR	N	030	060	E	120	150
STEER	003	031	061	090	122	147
FOR	S	210	240	W	300	330
STEER	179	209	241	270	298	334

Fig. 14. Compass Deviation Card.

The Deviation Card illustrated reads: "For N Steer 003". This means that on a heading N Magnetic, the compass has a 3° deviation west (Deviation West, Compass Best). It is therefore necessary to steer 003° by the Compass to make good a Magnetic Heading of North. And so on for the other points of the compass.

Some types of retractable undercarriages will be found to be magnetized to such an extent that they will cause considerable deviation of the compass when retracted. In such cases the compass must be swung in the air with the undercarriage retracted.

This can be done by the following simple method:

Select a road or railroad on the map whose bearing is as nearly as possible magnetic north and south, and one as nearly as possible magnetic east and west. Smooth air is essential and preferably no wind. Align the airplane heading on magnetic north by sighting up the north-south road or railroad. Set the Directional Gyro (DG). Hold the heading constant by DG and correct the magnetic compass to match the DG heading. Repeat the process on east.

The DG can now be used to align the airplane on the other headings and make the necessary corrections by the same method as that detailed above for swinging the compass on the ground.

Note: The directional gyro is subject to precession error. The airplane should not be flown more than 5 minutes without realigning the DG on one of the roads selected.

If a Driftmeter is available, the compass may be swung in the air with prevailing wind conditions. This, and other methods which require the use of special navigation equipment, such as the Astro Compass etc., are beyond the scope of this pilot-navigator text, but may be found in the many handbooks which deal more extensively with navigation.

If roads or railroads are scarce in the area, the airport runways may be utilized. Airport runway bearings are numbered to the nearest 10° magnetic and accurate bearings to the nearest degree should be obtained.

Note: The use of the Omnirange to establish magnetic headings for compass swinging is not recommended. The needle is not sufficiently sensitive for this purpose, except when close in to the station, and the VOR is subject to certain course errors.

Magnetic Dip

The Earth's Lines of Force are horizontal at the Equator but become vertical towards the Poles. This causes the compass to tend to **dip** in higher latitudes. See Fig. 8.

To compensate for dip, the magnet system is balanced pendulously on a pivot bearing with the centre of gravity of the system **below** or **lower than** the pivot point, **or** the top part of the pivot is so constructed that the centre of buoyancy of the system is well above its centre of gravity, **or** a combination of both methods. As one end of the magnet system begins to dip below the horizon the C of G is moved out of line with the pivot so that the weight of the system counteracts Z Force or, as one end of the magnet system tends to dip, the centre of buoyancy moves out of line with the pivot and C of G, counteracting Z Force. The resultant dip, in "normal" latitudes is about 2 or 3 degrees (Fig. 15). Note the relative positions of the pivot and centre of gravity and keep them in mind in the discussion of Northerly Turning Error, Acceleration and Deceleration Errors that follows.

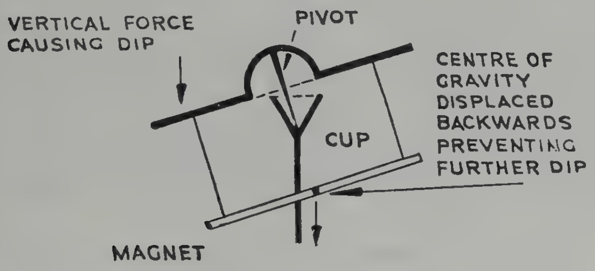

VERTICAL FORCE CAUSING DIP
PIVOT
CENTRE OF GRAVITY DISPLACED BACKWARDS PREVENTING FURTHER DIP
CUP
MAGNET

Fig. 15.

Northerly Turning Error

When an airplane in flight executes a normal turn, it banks and the wing on the inside is lowest. The plane of gyration of the magnetic system of the compass tends to maintain a position parallel to the transverse plane of the airplane due to the fact that the centre of gravity of the magnetic system is placed below the point at which the system pivots. As a result of the turn, the forces acting on the magnet system undergo certain changes which have a marked effect upon the direction-indicating properties of the compass, and under certain conditions large apparent deviations will be observed.

When an airplane is in straight and level flight, "H", the horizontal component of the earth's total force, is exerting its maximum influence, while "Z", the vertical component, is exerting a force in the vertical plane of the magnet system but can cause no deflection of the system. If the magnet system is tilted sideways through 90° (i.e. to the east or to the west), the system will take up a position under the combined influence of H and Z, parallel to the direction of the Lines of Force of the Earth's Magnetic Field at the position. But if the system is now turned in azimuth until its normal axis of rotation is parallel to the Meridian, H is no longer able to affect the magnet system, which will come entirely under the effect of Z, and will take up a vertical position, north-seeking end downwards in the northern hemisphere and upwards in the southern. Consequently, the north-seeking end of the magnet system will rotate towards the inside of the turn in the northern hemisphere (Centripetal Force which acts through the pivot towards the centre of the turn) and towards the outside in the southern (Centrifugal Force which acts through the centre of gravity towards the outside of the turn). This is the magnetic factor responsible for Northerly Turning Error.

There is also a mechanical factor which has a slight effect on the compass during turns. When the airplane commences a turn, the liquid in the compass bowl tends to turn with the bowl. This liquid swirl drags the magnet system with it, and causes a rotation of the system towards the centre of the turn.

The error is most apparent on headings of north and south. When making a turn from or towards a heading of north, the compass briefly gives an indication of a turn in the opposite direction and then corrects itself to turn with the airplane, but it under registers the turn (or lags). The compass is said to be "sluggish" in the northerly quadrant. When making a turn from or towards south, it gives an indication of a turn in the correct direction but at a much faster rate than is actually occurring. It over registers (or leads). In the southern quadrant, the compass is said to be "lively". The error is less pronounced in turns from south than from north.

The effect of Northerly Turning Error is greatest over the Poles and gradually decreases towards the Magnetic Equator, where it is zero. The deflection of the compass is maximum on north and south headings, and nil on east and west.

Knowledge of this characteristic of the magnetic compass, Northerly Turning Error, has been of invaluable assistance to pilots who have experienced loss of gyros, or who are flying an airplane that is not equipped with gyros, at a time when they have to fly by reference to instruments. In fact, the method was first used by World War I pilots. The method is to establish a south heading. The compass on south is very sensitive and leads any turn. Therefore, if the compass indicates that the airplane is turning, control movements should be applied to return it to its original heading. The tilt of the compass card will indicate when one wing is down.

Accurate turns onto any heading are quite simple if use is made of a Directional Gyro.

However, if there is no Directional Gyro, and turns *must* be made to north or south headings by reference to the magnetic compass, the following simple rules may prove helpful:

On turns towards north, N.T. Error causes the compass to lag.

On turns towards south, N.T. Error causes the compass to lead.

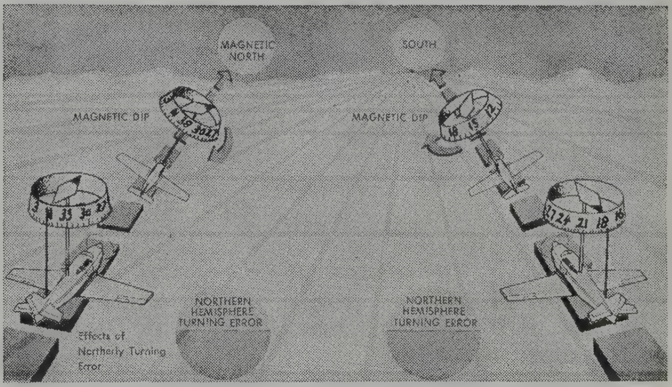

MAGNETIC NORTH
SOUTH
MAGNETIC DIP
MAGNETIC DIP
3
33
30
27
24
21
18
15
12
NORTHERN HEMISPHERE TURNING ERROR
NORTHERN HEMISPHERE TURNING ERROR
Effects of Northerly Turning Error

Fig. 16. Northerly Turning Error.

The lead or lag will vary proportionately with the latitude in which the flight is being conducted. For example: if the latitude is 40°N., the compass lag or lead will be 40°.

In making a turn towards north, stop the turn before reaching the desired heading. In making a turn, for example, to the left towards 0° in an area of latitude 45°N, allow 45° for the

Turning Error. It is also necessary to allow about 5° for 15° of bank. The roll out should be initiated, therefore, at 50°. The compass will read 0° (or 360°) when it catches up.

On turns towards south, continue the turn past the desired heading. In making a turn, for example, to the right towards 180° in an area of latitude 35°N, allow 35° for the Turning Error and 5° for 15° of bank. The roll out should be initiated, therefore, at 210°. The compass will read 180° when it settles back.

In making turns by this method, the angle of bank should not exceed 15°.

On turns **from** north and south, Northerly Turning Error gradually diminishes and is nil on east and west. It is necessary to interpolate for this.

The fact should be realized that, often in a turn, an airplane may be subject to gust loads which will further aggravate the constant behaviour of a compass. Under certain conditions, an airplane may be turning but the compass, being subject to outside forces, does not indicate a turn at all but maintains a constant heading. When the airplane levels out for straight and level flight, the compass will spin rapidly to indicate the new heading.

In an airplane with a turn and bank indicator, a pilot may make reasonably accurate turns to a particular heading by banking the airplane into a standard rate 1 turn and allowing 1 second for every 3 degrees of the compass (i.e. 30 seconds to turn 90 degrees).

While reading the compass when holding north or south headings, always make sure the wings are level and the turn needle is centred.

Acceleration and Deceleration Errors

When an airplane **increases** its speed, a force is set up in the direction in which the airplane is moving. This is **Acceleration** and will act through the pivot of the compass. The magnet system, however, tends to lag behind due to **Inertia** acting through the centre of gravity. On east and west headings, this causes a **Turning Moment,** tending to rotate the magnet system and so causing deflection of the compass card.

When the airplane **decreases** its speed, **Deceleration** causes a similar effect, but the deflection will be in the opposite direction.

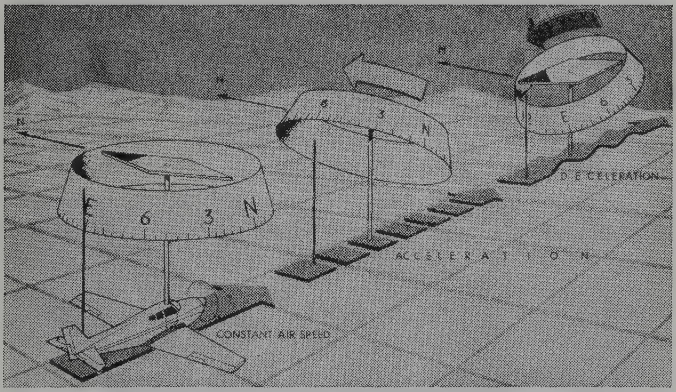


Fig. 17. Acceleration Error.

On E. and W. headings **Acceleration** causes the compass to register a turn towards **north.**

On E. and W. headings **Deceleration** causes the compass to register a turn towards **south.**

The deflection of the compass will occur only while the airplane is accelerating or decelerating. Immediately the airplane is again in equilibrium, the compass will return to its normal magnetic heading.

When reading the magnetic compass on east or west headings, always make sure that the airspeed is kept constant.

The effect of Acceleration and Deceleration Compass Error is nil on north and south headings.

THE ASTRO COMPASS

Close to the Magnetic Pole, the Earth's Magnetic Lines of Force dip *vertically* towards the Pole. The compass needle lies in a *horizontal* plane, and as the strength of the horizontal component of the Earth's Magnetic Field tends to disappear in the close vicinity of the Pole, the magnetic compass loses its ability to point the way, and becomes anything but a dependable companion. In a large area of Northern Canada the magnetic compass is therefore unreliable. Within this area, called the Northern Domestic Airspace, DOT regulations require that airplanes weighing 12,000 lbs. or over must be fitted with an Astro Compass or some other means of determining direction that is not dependent on a magnetic source. The Astro Compass is not influenced by the Earth's Magnetic Field, but indicates direction with reference to the Sun, Moon, Planets or Stars. These heavenly bodies have been man's guiding beacons in the skies since time immemorial. The examinations for Commercial, Senior Commercial and Transport Pilot licenses in Canada require a knowledge of the Astro Compass.

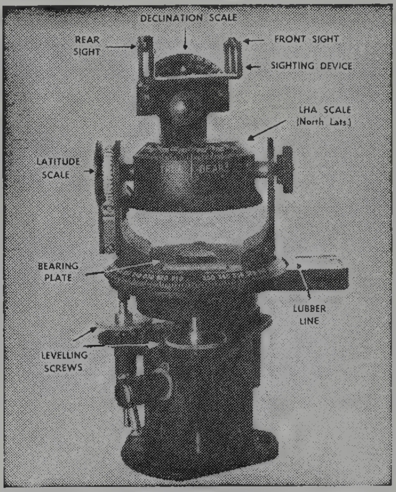


Fig. 18. The Astro Compass.

The Astro Compass is an instrument designed to enable a pilot or navigator to determine the True Heading of his airplane. (It can also be used to take a bearing on an object.)

In the simplest possible terms, the Astro Compass is a Bearing Plate with a movable Sighting Device mounted above it. The bearing of a heavenly body can be set on the bearing plate, and when the movable sights are properly aligned on the heavenly body, the North Mark on the bearing plate will coincide with True North. The bearing plate can now be read off against a Lubber Line (aligned in the fore and aft axis of the airplane) to indicate the True Heading. The Directional Gyro can now be set to the True Heading, and the airplane steered with reference to the Directional Gyro in lieu of the magnetic compass.

The Astro Compass will automatically find the true bearing (or azimuth) of a heavenly body if the following information is known:

1. The Latitude.
2. The Local Hour Angle of the body.
3. The Declination of the body.

The position in latitude and longitude must be derived through Dead Reckoning Navigation.

The position of the Sun, Stars and other astronomical bodies can be accurately predicted for any given moment of time. They are recorded in a handy volume called the **Air Almanac.** By opening the Air Almanac to the Greenwich date, hour and minute of time on which you wish to check your True Heading, you can look up the *Greenwich Hour Angle* and the *Declination* of the Sun, Moon, Aries, or the particular Planet you wish to sight on. The *Sidereal Hour Angle* and *Declination* of any navigation Star can similarly be found.

The GREENWICH HOUR ANGLE (GHA) of a heavenly body is the angular distance between the Greenwich Meridian and the Meridian of the body. It is measured *westward* through 360°.

The DECLINATION of a heavenly body is its angular distance north or south of the Celestial Equator (hence it corresponds to **latitude).** It is measured in degrees and minutes north or south of the Celestial Equator, the same as latitude.

THE SIDEREAL HOUR ANGLE (SHA) of a Star is the angular distance between the First Point of Aries and the Meridian of the Star measured *westward* from Aries through 360°.

The FIRST POINT OF ARIES (γ) sometimes referred to as the "Vernal Equinox", is a point on the Celestial Equator arbitrarily chosen as a reference point from which to measure the Hour Angles of the Stars.

To find the Greenwich Hour Angle (GHA) of a Star, look up the Sidereal Hour Angle of the Star in the Air Almanac and also the Greenwich Hour Angle of Aries. The GHA of the Star is the algebraic sum of both.

$$\text{GHA}☆ = \text{GHA } \gamma + \text{SHA}☆$$

The LOCAL HOUR ANGLE (LHA) of a heavenly body is the angular distance between your Meridian and the Meridian of the body, measured *westward.* It is the algebraic sum of the GHA of the body and your longitude.

$$\text{LHA} = \text{GHA} \begin{matrix} +\text{E} \\ -\text{W} \end{matrix} \text{ Longitude}$$

Fig. 19 illustrates Hour Angles.

Note: In measuring the hour angles of heavenly bodies, it is simpler to think of the position of the body as a point on the surface of the earth, rather than one in the sky — in other words, to bring the body down on the ground for convenience in measuring. Such a point is called the **Sub Stellar Point.** It is defined as the point on the surface of the earth directly beneath the heavenly body at any given instant of time and is where the line joining the body to the centre of the earth cuts the surface.

From the foregoing, it will be clear that to find True Heading by the Astro Compass, it is necessary to have a reasonable knowledge of position, to know the correct time (GMT) and to be able to get a sight on a heavenly body.

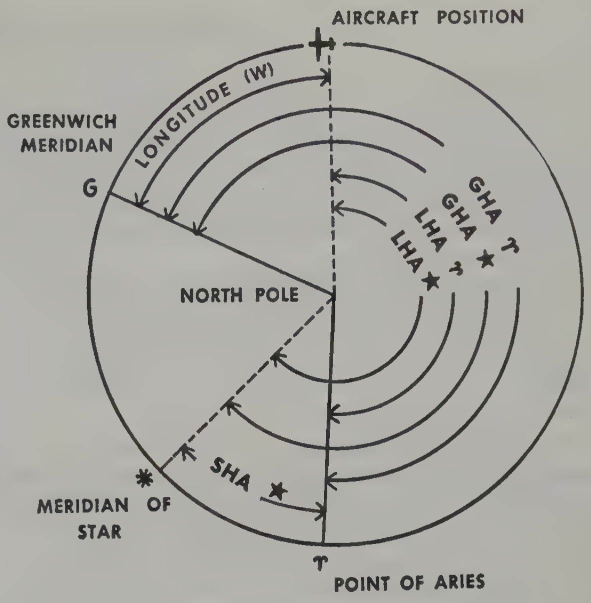


Fig. 19. Hour Angles.

The Astro Compass, in addition to the bearing plate and sighting device mentioned previously, has a number of movable drums and scales (Fig. 18).

To find True Heading by Astro Compass:

1. Level the instrument.
2. Set the latitude (nearest degree) on the Latitude Scale.
3. Set the Local Hour Angle of the body on the LHA Scale.
4. Set the Declination of the body on the Declination Scale.
5. Rotate the Bearing Plate until the body on which a sight is being taken is lined up in the Sighting Device.
6. Read the True Heading against the Lubber Line.

UNITS OF DISTANCE AND SPEED

A STATUTE MILE is a distance of 5280 feet.

A NAUTICAL MILE (6080 feet) is the average length of one minute of latitude. For all practical purposes it may be taken as the length of one minute of arc along any Great Circle.

A KNOT is a speed of one nautical mile per hour.

CONVERSIONS

SPEED

66 Nautical Miles = 76 Statute Miles.

To convert knots to mph., multiply knots by 1.15.

To convert mph. to knots, divide mph. by 1.15.

A scale of nautical miles (based on the scale of the chart at mid latitude) is printed on all I.C.A.O. aeronautical maps.

Practically all Circular Slide Rule computers have statute mile — nautical mile conversion indexes printed on the outer scale.

The abbreviation, officially adopted for nautical miles is "n.miles" or "n.m." — for statute miles, "s.miles" or "s.m."

HOURS AND MINUTES

To convert minutes to hours, divide by 60 (60 min. = 1 hr.) e.g. 30 min. equals 30 ÷ 60 = .5 hrs.

To convert hours to minutes, multiply by 60. e.g. .75 hrs. equals .75 X 60 = 45 min.

TIME IN FLIGHT.

To find the time in flight, divide the distance by the groundspeed. e.g., The time to fly 120 n. miles at a groundspeed of 80 knots is 120 ÷ 80 = 1.5 hrs. (The .5 hrs. × 60 = 30 min.)

Answer: 1 hr. 30 min.

DISTANCE.

To find the distance flown in a given time, multiply groundspeed by time. e.g. The distance flown in 1 hr. 45 min. at a groundspeed of 120 knots is 120 X 1.75 = 210 n. miles.

GROUNDSPEED.

To find the groundspeed, divide the distance flown by the time. e.g. An airplane flies 270 n. miles in 3 hrs. The groundspeed is 270 ÷ 3 = 90 knots.

AERONAUTICAL CHARTS

The Earth is a sphere and therefore its surface cannot be represented accurately on a flat plane. The map maker's problem can be readily appreciated by cutting a rubber ball in half — and then attempting to flatten out one of the halves in a flat plane.

Since the surface of a sphere cannot be accurately projected onto a map, a map must show the portion of the Earth's surface it represents with some distortion.

There are four basic elements in map construction. These are:

1. Areas.
2. Shapes.
3. Bearings.
4. Distances.

According to the particular purpose of a map, one or more of these elements is preserved as nearly correct as possible, with consequent unavoidable distortion in the remaining elements.

The mathematical bases on which maps are constructed are termed **Projections.**

There are two principal types of chart projections used in Air Navigation Charts, the **Lambert Conformal Conic Projection** and the **Transverse Mercator Projection.**

THE LAMBERT CONFORMAL CONIC PROJECTION

The basic idea upon which the Lambert Conic Projection is developed is that of supposing a cone to be superimposed over the surface of a sphere (Fig. 20). If the cone were opened and unrolled, the Meridians and Parallels would appear as shown in the sketch (Fig. 21).

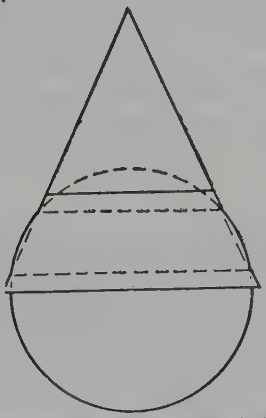


Fig. 20. Lambert Conformal Conic Projection.

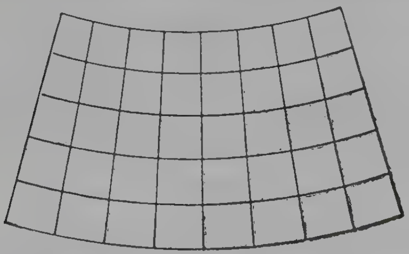


Fig. 21. Lambert Conformal Conic Development.

On the Lambert Conformal Conic Projection, the angles between Meridians and Parallels will be the same on the map as they are on the ground. The term "Conformal" refers to this characteristic. Scale must be the same along both Meridians and Parallels.

The properties of the Lambert Projection are:

1. Meridians are curves or straight lines converging towards the nearer Pole. If they are curves, the curvature is often so small as to be inappreciable.

The angle which one Meridian makes with another on the Earth is called **Convergency.** It varies with latitude. At the Equator there is no convergency between Meridians. At the Poles the Meridians converge at angles equal to the Change of Longitude between them.

2. Parallels of Latitude are curves which are concave towards the nearer Pole. On any but large scale maps, the curvature is considerable.

3. The scale of distance is practically uniform throughout the entire map sheet, the maximum distortion being not more than 1/2 of 1%.

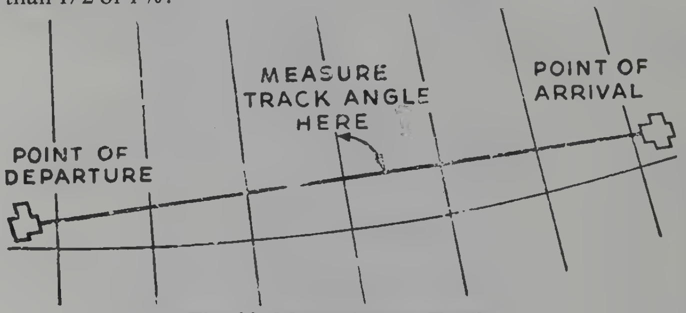


Fig. 22. Measuring the Track.

4. A straight line drawn between any two points on the map may be assumed, for all practical purposes, to represent **A Great Circle.**

Since a Great Circle does not cross every Meridian at the same angle, a straight line on the map will not be the same when measured on two or more different Meridians. Hence a straight line, or Great Circle Route, cannot be flown without changing heading at regular intervals.

To make good a given Track, or straight line, on this type of map it is necessary to change heading 2° for every 3° of longitude. Flying **east**, the 2° is added. Flying **west** it is subtracted.

For flights up to roughly 300 miles, the heading change referred to above may be averaged by measuring the Course or Track on the Meridian nearest the centre. (Fig. 22.)

The World Aeronautical Charts (WAC Charts) are based on Lambert Conformal Conic Projections.

THE TRANSVERSE MERCATOR PROJECTION

The principle on which the Mercator Projection is based is that of a cylinder which has its point of tangency at the Equator. Its approximate form may be visualized by imagining a light at the centre of a globe that casts a shadow of the Meridians and Parallels on a cylinder of infinite length enclosing it. As will be seen in Figs. 23 and 24, the shadows of the more northerly Parallels of Latitude will be cast wider apart on the cylinder than they actually are on the sphere.

The shadows of the Meridians on the cylinder will be straight and parallel lines to infinity, whereas on the sphere they converge to meet in a point at the Poles. It is, in other words, as though the Meridians were stretched apart at the Poles to the same distance they are apart at the Equator. This causes extreme exaggeration of longitude in northerly areas.

The principal characteristics of the Mercator Projection are:

1. Meridians are straight and parallel lines.
2. Parallels of Latitude are straight and parallel lines.
3. **A straight line drawn between any two points on the chart will represent a Rhumb Line.**
4. Owing to the method of projection, there is no constant scale of distance on a Mercator chart and areas are greatly exaggerated in high latitudes.

Mercator charts are, as a rule, graduated on the right and left hand sides for latitude, and at the top and bottom for longitude. The divisions of the longitude scale are only to be used

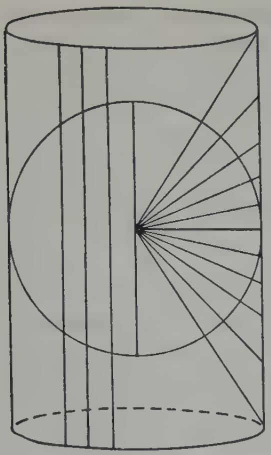


Fig. 23
Mercator Projection.

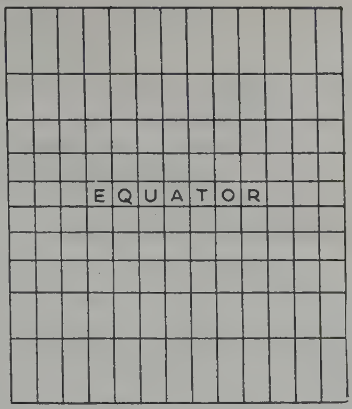


Fig. 24.
Mercator Development.

for laying down and taking off the longitude of a place. **The longitude scale must never be used for measuring distance.** Since 1 minute of latitude is always equal to one nautical mile, the latitude scale is used for measuring distance.

The Mercator Projection is relatively precise in depiction of distances in the equatorial regions. However, distortion, as has been stated, becomes more pronounced with distance from the Equator.

To overcome this problem, the Mercator technique can be applied by rotating the cylinder 90 degrees so that the point of tangency is a Meridian of Longitude rather than the Equator. In this case, the chart is accurate along the selected Meridian.

Such a projection is called a **Transverse Mercator Projection.**

The Transverse Mercator Projection, because of its method of production, is quite accurate in depicting scale, especially on charts covering a relatively small geographical area. Depending on the area to be depicted, any one of the 360 Meridians of Longitude can be selected as the point of tangency for the chart projection.

The Canadian Aeronautical (Pilotage) Charts are based on Transverse Mercator Projections.

TYPES OF AERONAUTICAL CHARTS

CANADIAN AERONAUTICAL (PILOTAGE) CHARTS

Canadian Aeronautical (Pilotage) Charts are designed primarily for visual navigation and are most useful during flight at lower altitudes and at slower speeds. Each chart depicts a portion of Canada and is identified by the name of the principal landmark on the chart. The Victoria-Vancouver Chart, for example, derives its name from the two cities that are its principal landmarks, although the map depicts the area from Victoria east to Princeton, B.C.

Aeronautical (Pilotage) Charts are based on the Transverse Mercator Projection and conform to the characteristics of that Projection.

The scale of the chart is 1:500,000 or about one inch to eight miles.

To keep pace with rapidly changing facilities, the charts are reprinted at regular intervals with updated information. The publication date is always shown with the Chart Identification.

The geographical chart itself is printed on one side only with the title and some airport information printed on the white borders. The legend of Basic Aeronautical Information is printed on the reverse.

WORLD AERONAUTICAL CHARTS

World Aeronautical Charts are designed also for visual navigation and are most useful during flight at the higher altitudes and at greater speeds. Each chart depicts a sizeable portion of the geographical area of Canada. Nineteen charts cover the whole country.

Each chart is identified by a letter and a number. For example, E 17 covers the area from Thunder Bay west to Regina, and from the 48th Parallel north to Thompson, Manitoba.

WAC Charts are based on the Lambert Conformal Conic Projection and conform to the characteristics of that Projection.

The scale of the chart is 1:1,000,000 or about one inch to sixteen miles.

The chart is printed on both sides of the sheet, the northern half of the area to be represented on one side and the southern half on the reverse. The title of the chart and other aeronautical information is printed on two sides of a white side border on one edge of the map.

VFR TERMINAL AREA CHARTS (VTA CHARTS)

VFR Terminal Area Charts are large scale charts (1:250,000) published for those airports in Canada that have Terminal Radar Service Areas (TRSA). Before entering a TRSA, a VFR flight must contact the appropriate ATC unit and receive clearance to enter the area. VTA charts depict VFR call up points outside the TRSA and VFR check points within the TRSA. Radio communication information and other information that is necessary for conducting flight through the TRSA is given on the chart. The edge of the TRSA is marked by a solid blue line. The edge of the Positive Control Zone is marked by a dashed blue line.

A more detailed discussion of Terminal Radar Service Areas is given in the Chapter **Aeronautical Facilities.**

ENROUTE RADIO FACILITY CHARTS

Enroute Radio Facility Charts are intended primarily for radio navigation over designated airway systems.

Enroute charts do not portray any cities, towns, or topographical features, but depict all radio navigation aids, including airways, beacons, reporting points, communication frequencies, etc.

Uncontrolled areas are tinted a basic light tan and controlled areas (such as airways, control zones, etc.) are shown in solid white. VHF facilities are overprinted in blue (including Omnirange stations, Victor Airways, etc.).

The directions, or bearings, of all airways (magnetic), distances between check points, minimum enroute altitudes, VOR change-over points, station identification letters, radio frequencies, and other pertinent radio navigation information is clearly shown in bold, easy to read characters.

The scale is not constant, but varies to suit the requirements of each individual chart, or series of charts.

Each chart contains two separate map sheets printed back to back. A table of map symbols and a list of all radio communication facilities available within the area covered by the charts is printed on the front sheet.

VFR CHART SUPPLEMENT

The VFR Chart Supplement is published jointly by Transport Canada and the Department of National Defence and lists all the aerodromes shown on Canadian Aeronautical Charts and World Aeronautical Charts for the area south of 60°N. The booklet is designed to be used in conjunction with these charts and should be carried by any pilot departing on a long cross country flight.

The Northern Supplement is a similar publication that lists all the airports in Canada north of 60°N.

The VFR Chart Supplement comprises three sections: Section A deals with Aerodromes and their Facilities; Section B with Heliports; and Section C with Flight Data and Procedures. As well there is a listing and an explanation of the abbreviations used in the book.

Section A lists all aerodromes alphabetically by the community in which they are located. A sketch of the airport is included showing the runway layout, taxiways, location of buildings and tower (if present).

The name of the aerodrome is given and its geographical co-ordinates listed. Its distance and direction from the community is given as is the time conversion from Greenwich Mean Time.

The aerodrome operator is listed with the appropriate telephone number. Information about the type of license the aerodrome has is given. If the aerodrome is a Customs Airport of Entry, that is stated.

Information about the services available is given (fuel, oil, storage, servicing, public facilities, etc.).

The lighting that is available is listed in a code that is explained in the section of the booklet called Abbreviations.

Radio communication facilities are listed (Radio, Tower, Ground, etc.) if they are available.

Weather services are listed.

A final Remarks Section indicates any special procedures that are applicable to the particular aerodrome.

REGINA SASK 72NE 72SE E-16
50 26N 104 40W 2SW GMT—6 **CYQR**
OPR– MOT, 306-526-8207 Pub Lic
Cstms: (1) AOE-A
Flt Plan & NOTAM: 306-522-4770
Wx: 306-569-5742
SERVICES– Fuel: 80,100,F40,JB
(CON G IP F40) **Oil:** All **S:** 1,2,3
AES: (2) C **PF:** A
LIGHTING– B, 4,5,6,7,9,10,WI,
07-AD(AS TE Hi), 12-AE(TE Hi),
25-AD(TE Hi), 30-AD(AS TE Hi) V2.5°
COMM– RADIO: 290T 126.7 122.2 122.1R
114.2T 286.2 (E) **TWR: (3)** 118.3
122.5R 236.6 (E) **GND: (3)** 121.9 275.8
WEATHER– W1 H+17 & 47 on 290 NDB
& 114.2 LUMSDEN VORTAC
REMARKS– (1) Avbl 14-06Z dly. **(2)** Avbl 13-05Z; O/T 2 hour PNR on a cost recovery basis. **(3)** Opr 13-06Z dly; O/T AAS from Regina Aeradio.

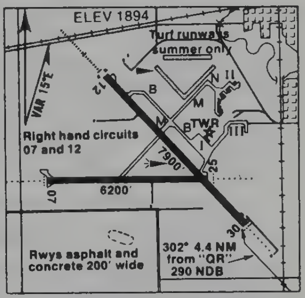


Fig. 25. Regina Airport.

Section B lists all heliports alphabetically by the community in which they are located.

The format used in giving information about heliports is identical to that used for Aerodromes.

Section C comprises a listing of information and procedures that every pilot should know and understand to achieve safe and efficient flight operations. The following subjects are covered: Special Procedures — Terminal Areas; Aerodromes Information and Procedure; Air Traffic Control; Special Airspace and Area Procedures; Radio Navigation Aids and Communication; Pilot Reports; Search and Rescue Procedures; Aeronautical Charts and Publications; VFR Chart Updating; Bird Hazards to Aircraft; and Emergency Procedures.

BASIC CHART INFORMATION

SCALE

The scale of the map is the relationship between a unit distance (i.e. one inch) on the map to the distance on the Earth that the unit represents. On most aeronautical charts the scale is expressed as a representative fraction.

Canadian Aeronautical Charts have a scale of 1:500,000, that is, one inch on the map is equal to 500,000 inches on the ground (or approximately one inch to 8 miles).

World Aeronautical Charts have a scale of 1:1,000,000, that is, one inch on the map is equal to 1,000,000 inches on the ground (or approximately one inch to 16 miles).

A Graduated Scale Line also gives scale information. On aeronautical charts, three such scale lines are printed on the border of the chart. One line represents kilometres, one statute miles and the other nautical miles. A Scale Line based on one inch to 8 miles is represented in Fig. 26.

A Conversion Scale for converting feet to metres is also printed on the margin of aeronautical charts.

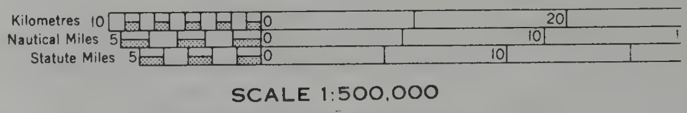


Fig. 26. A Graduated Scale Line.

LATITUDE AND LONGITUDE

A graticule (grid-like pattern of Meridians and Parallels) is depicted on aeronautical charts. The Meridians are graduated in minutes of latitude, and the Parallels in minutes of longitude. This makes it possible for latitude and longitude to be measured on the chart. In addition, the subdivided Meridians provide a scale of nautical miles, since a minute of latitude may be considered as a nautical mile.

On Canadian Aeronautical (Pilotage) Charts, the Meridians of Longitude and the Parallels of Latitude shown on the chart are numbered on the borders. Parallels are also conveniently numbered within the body of the chart. Meridians and Parallels, at 30' intervals, are divided into 1 minute divisions.

On WAC Charts, each Meridian of Longitude and Parallel of Latitude printed on the body of the map is marked off in minutes of latitude and longitude. The numbers of each Parallel and Meridian appear frequently on the graticule.

RELIEF

The representation of relief, or ground elevation above sea level, on aeronautical maps is of primary importance. On maps used for air navigation, it is essential that height and position of the highest parts of hills and mountains should be clearly shown, and that sufficient detail should be given to make easy the recognition of prominent features.

Relief is shown by contour lines, layer tinting and spot heights.

Layer Tinting

The map is coloured to represent different levels of elevation. On the white border of every map, an elevation legend is printed to show what colours are used for different elevations.

On Canadian Aeronautical Charts, the legend is called a Hypsometric Tint Scale. See Fig. 27. Green is used to represent elevations from sea level to 1000 feet. A lighter green represents elevations to 2000 feet and shades of light tan to a dark tan or bronze represent succeeding 1000 foot elevations.

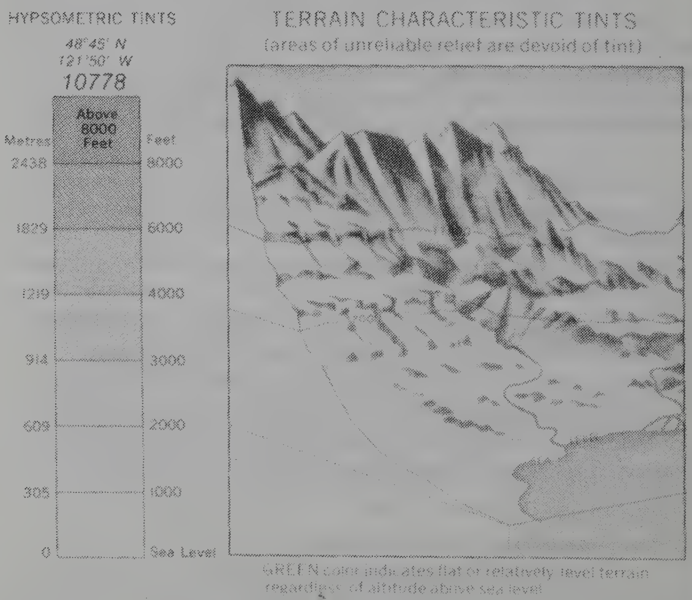

HYPSOMETRIC TINTS
48°45' N
121°50' W
10778
Above 8000 Feet
Metres
Feet
2438
8000
1829
6000
1219
4000
914
3000
609
2000
305
1000
0
Sea Level
TERRAIN CHARACTERISTIC TINTS
(areas of unreliable relief are devoid of tint)
GREEN color indicates flat or relatively level terrain
regardless of altitude above sea level

Fig. 27. Layer Tinting Legends.

On WAC Charts, a coloured pictorial scene gives Terrain Characteristic Tints. The colour coding ranges from green to light brown to dark brown to yellow for the highest elevations.

All bodies of water including rivers and streams are coloured blue.

Where differences in elevation are considerable, a layer tinted map is very easily read, since the relief stands out as on a model, but it is not possible to show minor variations of height, and the impression may be that the ground within the tinted areas is level.

Contours

Contour lines are drawn on a chart joining points of equal elevation above mean sea level. The height of a contour line (in feet) is indicated on the map by figures. The gradient (steepness) of a slope is indicated by the horizontal distance between the contour lines. The closer the contours, the steeper the slope of a hill or valley.

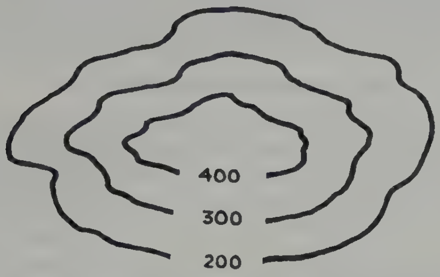


Fig. 28. A Hill represented by Contour Lines.

Spot Heights

Figures printed on a map show the height above sea level at any particular point. Especially high elevations are marked by a dot with the spot height beside the dot. The higher the elevation of the hill represented by a spot height, the larger in size are the numerals indicating its elevation. The highest spot on a particular map is represented by the largest size of numerals and the numeral is boxed with the layer tinting removed within the box.

The highest elevation on a particular chart is also indicated on the white border of the chart. On a Canadian Aeronautical Chart, it is shown at the top of the Hypsometric Tint Legend (See Fig. 27). On WAC Charts, the highest elevation with its geographical co-ordinates is printed as shown in Fig. 29.

RELIEF PORTRAYAL

Elevations are in feet

HIGHEST TERRAIN elevation is ***12972*** located at ***53°07′N 119°09′W***

Fig. 29.

ISOGONIC LINES

Isogonic lines (lines joining places of equal magnetic variations) are depicted by dashed blue lines. The degree of variation is printed at regular intervals along the line.

COMMUNITIES, ROADS, RAILWAYS

Yellow squares represent towns and small villages. Hamlets are represented by small circles. A city is depicted by a yellow area outlined in black that corresponds to the actual shape and size of the community.

Highways are indicated by red (Canadian Aeronautical Charts) or brown (WAC Charts) lines. Double lane highways are indicated by double lines. Railways are shown as black lines.

AERODROMES

Small airports are shown by a circle as depicted in Fig. 31. Larger airports (those with hard surface runways) are depicted at their location on the chart by a diagram of the landing areas. For airports with a control tower, a schematic depiction of the airport is repeated on the white border of Canadian Aeronautical Charts (Fig. 30). Information about all the aerodromes located within the area depicted by the chart is printed on the bottom border of the chart.

On WAC Charts, the schematic depiction of a large airport with paved runways appears at its geographic location on the chart and the airport information appears in a box adjacent to the airport.

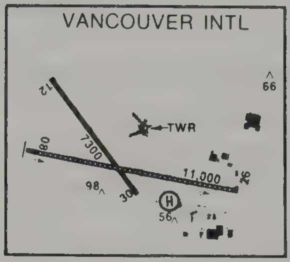


Fig. 30.

RESTRICTED AREAS

Areas over which flight is restricted are marked on aeronautical charts and information about them printed on the margin of the chart. These include Alert, Danger, Restricted, Warning and Prohibited Areas and Military Climb Corridors.

COMPASS ROSE

A circle overprinted on a chart divided into 360°, from which directions may be measured, is called a Compass Rose. The centre of the Compass Rose is a transmitting navigational facility such as a VOR or a TACAN station. The Compass Rose is oriented on the chart on Magnetic North.

A more detailed study of Radio Navigation Facilities appears in the Chapter **Radio Navigation.**

AERONAUTICAL INFORMATION

A legend of aeronautical information appearing on a chart always is printed somewhere on the sheet. On Canadian Aeronautical (Pilotage) Charts, it appears on the reverse side. On WAC Charts, it appears on the white side border. This legend includes information on Aerodromes, Radio Facilities, Airways and Control (See Fig. 31).

PLOTTING INSTRUMENTS

THE NAVIGATION PLOTTER

Of great assistance to a pilot in plotting and planning flights is an instrument such as the Navigation Plotter. It combines a protractor and a straightedge in one device which also incorporates a mileage scale for both 8 mile and 16 mile to the inch charts.

The Plotter is made of clear plastic so that details of the chart can be seen through it.

With the straightedge, the pilot can draw his track from his airport of departure to his planned destination.

The direction of a track is determined by using the protractor portion of the Plotter. It is numbered from 0° to 180° on the outside scale and from 190° to 360° on the inside scale. The outside scale is used for easterly tracks and the inside scale for westerly tracks.

To use the Plotter, place the hole in the centre of the Plotter over an intersection of the track line and one of the longitude lines on the chart. A point somewhere near the mid point of the track is best chosen to obtain greater accuracy.

Place a pencil point through the hole and rotate the Plotter until the top edge of the straightedge is aligned with the track line.

Read the true track heading where the longitude line of the

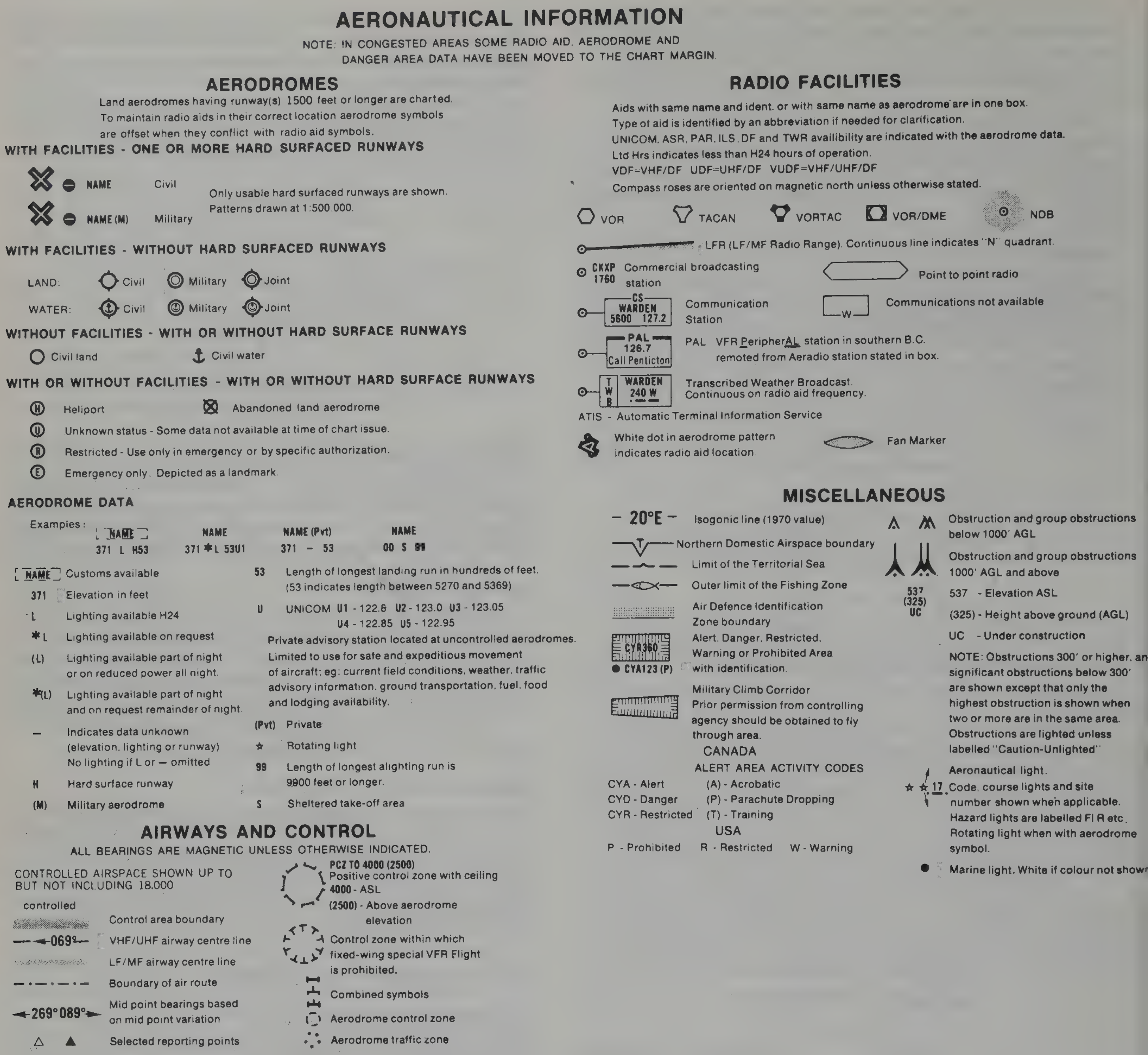

AERONAUTICAL INFORMATION
NOTE: IN CONGESTED AREAS SOME RADIO AID, AERODROME AND DANGER AREA DATA HAVE BEEN MOVED TO THE CHART MARGIN.
AERODROMES
Land aerodromes having runway(s) 1500 feet or longer are charted.
To maintain radio aids in their correct location aerodrome symbols are offset when they conflict with radio aid symbols.
WITH FACILITIES - ONE OR MORE HARD SURFACED RUNWAYS
NAME Civil
NAME (M) Military
Only usable hard surfaced runways are shown.
Patterns drawn at 1:500,000.
WITH FACILITIES - WITHOUT HARD SURFACED RUNWAYS
LAND: Civil Military Joint
WATER: Civil Military Joint
WITHOUT FACILITIES - WITH OR WITHOUT HARD SURFACE RUNWAYS
Civil land
Civil water
WITH OR WITHOUT FACILITIES - WITH OR WITHOUT HARD SURFACE RUNWAYS
Heliport
Abandoned land aerodrome
Unknown status - Some data not available at time of chart issue.
Restricted - Use only in emergency or by specific authorization.
Emergency only. Depicted as a landmark.
AERODROME DATA
Examples:
NAME 371 L H53
NAME 371 *L 53U1
NAME (Pvt) 371 - 53
NAME 00 S 99
NAME Customs available
371 Elevation in feet
L Lighting available H24
*L Lighting available on request
(L) Lighting available part of night or on reduced power all night.
*(L) Lighting available part of night and on request remainder of night.
— Indicates data unknown (elevation, lighting or runway) No lighting if L or — omitted
H Hard surface runway
(M) Military aerodrome
53 Length of longest landing run in hundreds of feet. (53 indicates length between 5270 and 5369)
U UNICOM U1 - 122.8 U2 - 123.0 U3 - 123.05 U4 - 122.85 U5 - 122.95
Private advisory station located at uncontrolled aerodromes. Limited to use for safe and expeditious movement of aircraft; eg: current field conditions, weather, traffic advisory information, ground transportation, fuel, food and lodging availability.
(Pvt) Private
☆ Rotating light
99 Length of longest alighting run is 9900 feet or longer.
S Sheltered take-off area
AIRWAYS AND CONTROL
ALL BEARINGS ARE MAGNETIC UNLESS OTHERWISE INDICATED.
CONTROLLED AIRSPACE SHOWN UP TO BUT NOT INCLUDING 18,000
controlled
Control area boundary
069° VHF/UHF airway centre line
LF/MF airway centre line
Boundary of air route
269° 089° Mid point bearings based on mid point variation
Selected reporting points
PCZ TO 4000 (2500) Positive control zone with ceiling
4000 - ASL
(2500) - Above aerodrome elevation
T Control zone within which fixed-wing special VFR Flight is prohibited.
Combined symbols
Aerodrome control zone
Aerodrome traffic zone
RADIO FACILITIES
Aids with same name and ident. or with same name as aerodrome are in one box.
Type of aid is identified by an abbreviation if needed for clarification.
UNICOM, ASR, PAR, ILS, DF and TWR availibility are indicated with the aerodrome data.
Ltd Hrs indicates less than H24 hours of operation.
VDF=VHF/DF UDF=UHF/DF VUDF=VHF/UHF/DF
Compass roses are oriented on magnetic north unless otherwise stated.
VOR
TACAN
VORTAC
VOR/DME
NDB
LFR (LF/MF Radio Range). Continuous line indicates "N" quadrant.
CKXP 1760 Commercial broadcasting station
Point to point radio
CS WARDEN 5600 127.2 Communication Station
W Communications not available
PAL 126.7 Call Penticton
PAL VFR PeripherAL station in southern B.C. remoted from Aeradio station stated in box.
T W B WARDEN 240 W Transcribed Weather Broadcast. Continuous on radio aid frequency.
ATIS - Automatic Terminal Information Service
White dot in aerodrome pattern indicates radio aid location.
Fan Marker
MISCELLANEOUS
— 20°E — Isogonic line (1970 value)
T Northern Domestic Airspace boundary
Limit of the Territorial Sea
Outer limit of the Fishing Zone
Air Defence Identification Zone boundary
CYR360 CYA123 (P) Alert, Danger, Restricted, Warning or Prohibited Area with identification.
Military Climb Corridor
Prior permission from controlling agency should be obtained to fly through area.
CANADA
ALERT AREA ACTIVITY CODES
CYA - Alert
CYD - Danger
CYR - Restricted
(A) - Acrobatic
(P) - Parachute Dropping
(T) - Training
USA
P - Prohibited
R - Restricted
W - Warning
Obstruction and group obstructions below 1000' AGL
Obstruction and group obstructions 1000' AGL and above
537 (325) UC
537 - Elevation ASL
(325) - Height above ground (AGL)
UC - Under construction
NOTE: Obstructions 300' or higher, an significant obstructions below 300' are shown except that only the highest obstruction is shown when two or more are in the same area. Obstructions are lighted unless labelled "Caution-Unlighted".
17 Aeronautical light.
Code, course lights and site number shown when applicable. Hazard lights are labelled Fl R etc. Rotating light when with aerodrome symbol.
Marine light. White if colour not show

Fig. 31. Aeronautical Information Legend.

chart intersects the scales. (Use the outer scale for easterly tracks and the inner scale for westerly tracks.)

For measuring tracks that are almost directly north and south, a latitude line may be used as a line of reference and the small scale at the centre of the protractor used to determine the heading.

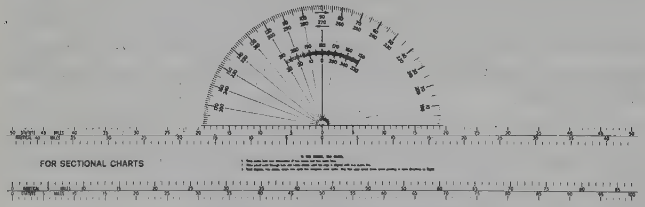


Fig. 32. Navigation Plotter.

In using the straightedge to determine the distance from the airport of departure to the destination, be sure to use the correct side of the straightedge for the type of chart in use. The mileage scale on one side of the straightedge is 1:500,000 for Pilotage Charts and is marked off in both statute and nautical miles. The reverse side of the straightedge has a scale of 1:1,000,000 for WAC Charts and is also marked off in both statute and nautical miles.

THE DOUGLAS PROTRACTOR

A Navigation Plotter, such as that described above, is not the only instrument that can be used to plot tracks. A simple protractor and a ruler will serve the purpose just as well.

The Douglas Protractor, being square, can be used both for determining heading and as a straightedge. The instrument has a compass rose graduated in 360° marked around the outer edges. It is transparent so that when placed on a map, the map is visible through it.

The method of measuring a Course or Track on a map is shown in Fig. 33. Place the Protractor on the map with the hole in the centre lying on the Track at a point **where the north-south line on the Protractor lies along the Meridian.** If this is not con-

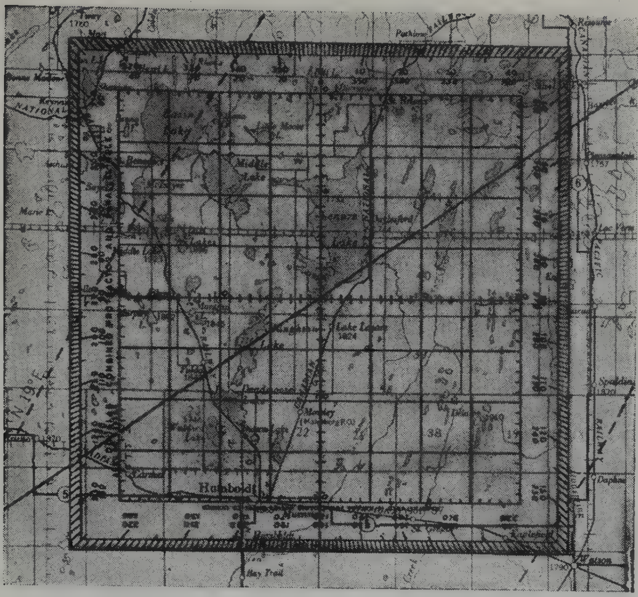


Fig. 33. The Douglas Protractor.

venient, one of the parallel lines may be lined up parallel with the nearest Meridian. The Track is read off where it cuts the edge of the Protractor — in this case 56° in one direction, or 236° in the opposite direction.

RULER

In addition to a Protractor, a pilot will require a ruler to measure distance. A mileage scale is printed on every aeronautical chart and it is a simple matter to measure the distance from the airport of departure to the destination and lay this distance off against the chart scale to determine the mileage. The distance scales on ICAO charts in a given series are nearly, but not exactly constant, and are also affected by humidity. A ruler which is constructed mathematically to scale may not exactly correspond to the map sheet you are using. For practical air pilotage purposes, the difference is inappreciable. For extreme accuracy, note the difference between the ruler and the map scale at the 100-mile mark and apply it.

MAP READING

Map reading, either on the ground or in the air, calls for a clear understanding of the scale of the map and a "sense" of that scale — in other words, a sense of proportion. It also requires an understanding of the direction of True or Magnetic North and of the symbols used on the map.

The direction of north should never be in doubt. Remember that the right and left hand edges of the map sheet are not always parallel to the Meridians.

The magnetic variation is generally clearly stated on Aeronautical Charts. On flights up to 300 miles, the variation should be averaged for the entire route. This is done by using the isogonic line which intersects the track (as nearly as possible) midway between the point of departure and the destination. On flights of longer duration, the heading should be altered at regular intervals to allow for accumulated changes in variation.

The key to a chart is the title. This should be read through carefully. In the title, the locality covered, the scale, the date of survey, and a list of conventional signs and abbreviations will be found.

FOLDING A MAP OR CHART

A map should be folded into a strip about eleven or twelve inches wide with the Track lying somewhere about the centre of the strip.

It should then be folded "accordion" fashion, so that successive portions of the Track can be read by turning the folds over one by one (Fig. 34).

If more than one map sheet is used, the sheets should be numbered and arranged in the order in which they will be required. This is important.

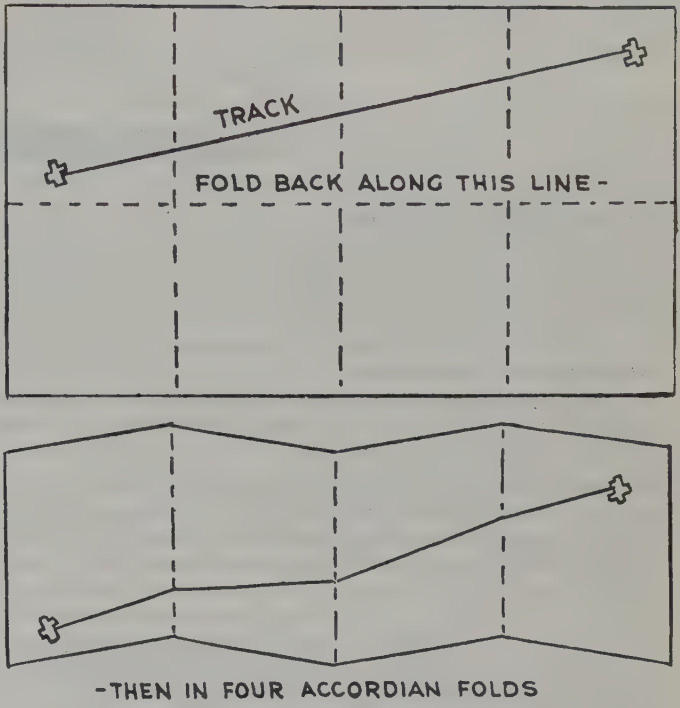


Fig. 34. Folding map for use in flight.

LANDMARKS

Water — Can be seen at great distance and offers the best landmark of all. During wet seasons it must be remembered that flood areas may easily be mistaken for lakes. Some rivers and streams may be obscured by trees in summer and therefore be hard to identify.

Heights of Land — Can be seen for very great distances but are not as numerous as other landmarks.

Roads — It is sometimes difficult to distinguish main roads from unimportant ones since even secondary roads are sometimes paved. Double lane throughways are very noticeable and are especially good landmarks. The intersection of two main roads is also a good landmark.

Railway Lines — These do not show up as clearly as roads, but are less numerous and therefore serve as distinctive and useful landmarks. Railway crossings or junctions are especially prominent and present distinctive patterns.

Towns — Towns can usually be readily identified by shape, and particularly by the pattern of roads or railway lines entering or leaving them. The general colour of towns varies in different districts. Smoke haze over larger cities makes them sometimes very difficult to recognize, particularly in dull weather and when approaching them towards the sun.

Golf Course and Race Tracks — These are both fairly good landmarks and are possible emergency landing grounds for airplanes having reasonably low landing speeds.

FLYING BY MAP READING

Skill in map reading does not begin and end in the ability to pick out conspicuous landmarks and locate them on the map.

Further, and most emphatically, **it does not consist of following rivers, railways, etc., around.** When visibility is normal, a well-trained pilot should be able to fly a direct route to his destination by map reading alone.

Map reading is a great deal more difficult at low altitudes than it is at higher ones, due to the relative nearness of the horizon, and to the fact that the pilot cannot see enough of the terrain at one glance to enable him to relate what he sees to what is on his map. When first practising map reading and cross country navigation, flights should be conducted at, at least, 2 or 3 thousand feet above the ground.

When flying by map reading, it is advisable to orient the map to the direction in which the airplane is proceeding along its route, even though this may mean that the lettering on the map is sideways or upside down.

NAVIGATION PROBLEMS

NAVIGATION TERMS

WIND is air in motion, especially a mass of air having a common direction or motion. Wind moves horizontally. (A movement of air vertically is called a current.)

INDICATED AIRSPEED is the airplane's speed as indicated by the airspeed indicator.

TRUE AIRSPEED is the speed of the airplane relative to the air. It is indicated airspeed corrected for the airspeed indicator error due to density and temperature.

GROUNDSPEED is the speed of the airplane relative to the ground. An airplane is affected by wind. If there is no wind at all, true airspeed and groundspeed will be the same. If, however, an airplane is flying in an air mass that is moving in the same direction, the airplane will have a tailwind that will help its progress over the ground, with the result that its groundspeed is in excess of the true airspeed. Conversely, a head wind will impede the progress of the airplane over the ground with the result that the groundspeed is slower than the true airspeed.

DRIFT is the lateral displacement of an airplane from its heading, due to the effect of wind. A wind blowing from either the starboard or port sides of an airplane will cause the airplane to drift away from its intended track.

The HEADING of an airplane is the angle between the longitudinal axis of the airplane at any moment and a Meridian. In other words, it is the direction the nose of the airplane is pointing, measured from an imaginary line running north and south. If the Heading is measured from a True Meridian, it is referred to as a **True Heading,** if from a Magnetic Meridian, as a **Magnetic Heading.** If it is measured from the direction of a Compass Needle, it is referred to as a **Compass Heading.** The angle is measured **clockwise** through 360°.

The TRACK (intended) is the direction an airplane intends to travel over the ground. The intended Track may be represented by a straight line drawn on a map. Its direction is the angle between this line and a Meridian measured clockwise through 360°. As in the case of Headings, Tracks are named **True, Magnetic or Compass** with reference to the Meridian from which they are measured.

The DRIFT ANGLE is the angle between the Heading of an airplane and its Track. In other words, it is the angle at which the pilot heads the airplane across the track to keep the wind from blowing him off the track.

The TRACK MADE GOOD is the actual path travelled by the airplane over the ground. Like the Intended Track, it may be represented by a line drawn on a map and (provided it is a reasonably straight line) its direction measured from a True or Magnetic Meridian or Compass North.

A TRUE MERIDIAN is a Meridian on the surface of the earth joining the True North and South Poles. On practically all maps used for air navigation purposes the True Meridians are shown.

A MAGNETIC MERIDIAN is the direction in which a Compass Needle will lie when influenced only by the Earth's Magnetic Field. In actual practice Magnetic Meridians are not shown on maps but are found by adding or subtracting the variation at any particular place to or from the true Meridian. (Variation is indicated on maps by isogonic lines, which are lines joining all places of equal variation.)

COMPASS NORTH is the direction in which a particular Compass Needle will lie when influenced by both the Earth's Magnetic Field and local magnetic influences (deviation) in the airplane. The actual reading on a compass at any time is the angle between Compass North and the direction the airplane is heading.

AZIMUTH means *direction* measured as an angle clockwise from a Meridian. It is the same as a Bearing. The Azimuth, or Bearing may be True, Magnetic or Compass.

THE COMPOSITION OF VELOCITIES

The **Velocity** of a body is the **rate of change of position** of a body in a **given direction,** hence it involves both speed and direction.

A velocity may be represented by a straight line. The direction may be shown by the direction of the line and the speed by the length of the line to scale.

The straight line referred to above which represents the velocity of a body may also be referred to as a "Vector". A **Vector** may be defined as a **quantity having both magnitude and direction.** In aviation, vectors almost invariably represent speed and direction, or in other words, velocity.

A body may be subjected to two or more velocities at the same time and these may not act in the same straight line.

For example, an airplane may be flying on a heading due North at 80 mph with a wind blowing from the West at 20 mph. The airplane will have two velocities, one towards the North at 80 mph and the other towards the East at 20 mph.

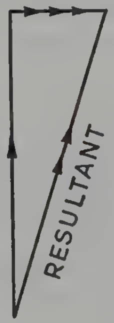


Fig. 35. Composition of Velocities.

These two velocities are equivalent to a single velocity which is called the **Resultant.** The Resultant, in this case, would represent the Track and Groundspeed of the airplane (Fig. 35).

When the Components act in the same straight line, the Resultant is obtained by addition or subtraction. When the Components act in other than the same straight line, the Resultant may be found by a **Triangle of Velocities.**

THE TRIANGLE OF VELOCITIES

If a moving point possesses, simultaneously, velocities representing speed and direction, these may be represented by two sides of a triangle (AB and BC in Fig. 36). They are, then, equivalent to a Resultant Velocity represented by the third side (AC).

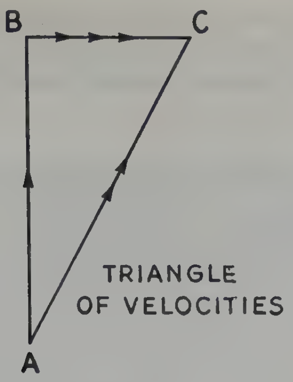


Fig. 36.

Note: Arrowheads should always be used to show the direction of the Components clearly. A single arrowhead represents the Heading of the airplane. Double arrowheads represent its Track. Triple arrowheads indicate the Wind.

The solution of navigational wind and drift problems is based on the principal of the Triangle of Velocities.

The **Heading and Airspeed** of an airplane can be represented by one side of a triangle. The **Wind and Windspeed,** drawn to the same scale, can be represented by another, and the **Track and Groundspeed** by the third.

A knowledge of any four of these is sufficient to complete the triangle, from which the remaining two may be determined.

THE FLIGHT COMPUTER: WIND SIDE

Wind and drift problems may be solved on navigation computers in a fraction of the time it takes to plot them on paper. Although such a computer is somewhat costly, the investment is small compared to the total cost of learning to fly. All pilots should be able to use a navigational computer and this section is written with the assumption that students have a computer available. The types of navigation computers in use are too many and varied to be dealt with individually here.

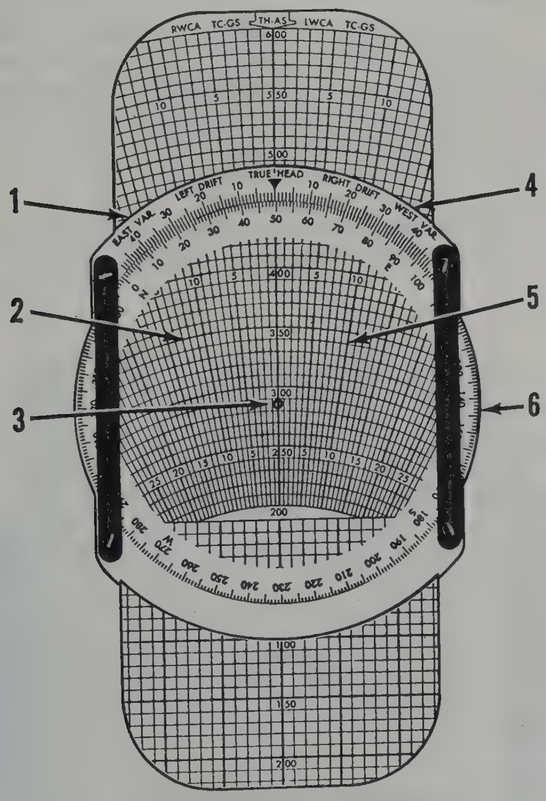


Fig. 37. The Dalton Computer.

1. Variation Scale.
2. Speed Lines.
3. Grommet.
4. Drift Scale.
5. Drift Lines.
6. Compass Rose.

One of the most widely used is the Dalton Dead Reckoning Computer. One side of the Computer is a Circular Slide Rule. The other side is the Wind Drift Computer (shown in Fig. 37). The Wind Side of the Computer is used to solve the wind and drift problems that follow.

The instrument has a **Compass Rose** which can be rotated. The dial inside the Compass Rose is a transparent window on which pencil marks can be made, and erased. In the centre of the window is a dot with a ring around it, the **Grommet,** which is a reference point used in plotting. Through the window can be seen a grid marked out in concentric arcs and radial lines. This is printed on a sliding plastic strip. The concentric arcs represent speed in mph or knots and will be referred to as **Speed Lines.** The radial lines represent degrees of drift to right or left, and will be referred to as **Drift Lines.** At the top is a scale graduated in degrees of drift to right or left, the **Drift Scale.** This may also be used as a **Variation Scale** to apply magnetic variation, east or west. In the centre is an index referred to as the **True Head** (True Heading Index).

Any navigation problem which can be plotted can be solved on the computer, including multiple drift, off-course, radius of action, interception, etc. Basic problems of primary interest to the pilot-navigator only are dealt with in the text which follows.

WIND AND DRIFT PROBLEMS

PROBLEM 1.

To find the Heading to steer to make good a given Track and to find the Groundspeed when the Airspeed and the wind and windspeed are known.

A Skylark Deluxe is to proceed from Niagara Falls to Toronto Island Airport. The Intended Track (True) is 332°. The true airspeed of the airplane is 85 knots. The wind is 280° (True) at 25 knots. (Note: the direction **from which the wind blows** is always given.) What is the Heading to steer and what is the Groundspeed?

Solution by Plotting

First draw a vertical line to represent a True Meridian on your plotting paper and mark the scale you are using in one corner. This applies to the solution of all wind and drift problems.

1. From A draw A-B, 332°, to represent the True Track (Fig. 38).

2. From A draw A-C at 280° to the Meridian but downwind from A. The line A-C, therefore is drawn at an angle of 100° to the True Meridian. Draw the line A-C 25 n. miles to scale to represent the wind and windspeed.

3. With C as centre and radius 85 n. miles (the true airspeed) describe an arc cutting A-B at D. Join C-D.

Therefore, in the triangle A-C-D, A-C represents the wind and windspeed, C-D the heading and true airspeed, and A-D the track and groundspeed.

The Heading to Steer is the angle C-D makes with the Meridian, which is 319°. This heading will be correct whatever the distance to be flown, so long as the wind and the airspeed of the aircraft remain constant.

The Heading to Steer by compass is found by applying the variation and deviation to the True Heading.

The drift is the angle between the Heading and the Track. In this case, it is 13° to starboard.

The length of the line A-D represents the ground speed, which is 67 kts.

The time taken is found by dividing the total distance by the groundspeed and multiplying by 60. Toronto Island is 39 n. miles from Niagara Falls. The estimated elapsed time would therefore be:

$$(39 \div 67) \times 60 = 35 \text{ minutes.}$$

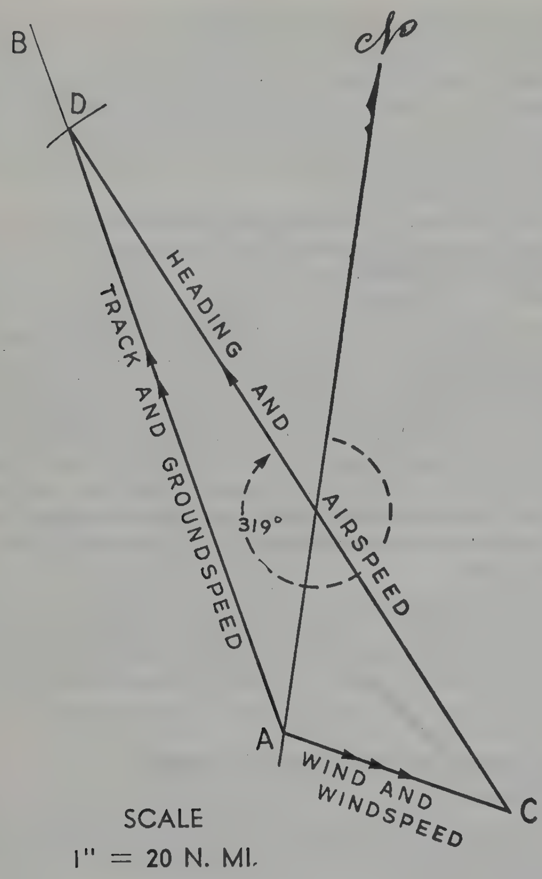


Fig. 38.

Solution By Computer

1. Set the Wind Direction (280°) on the compass rose opposite the True Head Index.

2. Move the slide so that any convenient whole number shows under the grommet (centre of the disc).

3. Draw a line **down** from the grommet 25 units in length to represent the Wind Speed and draw an arrow at the end of the line.

4. Move the slide so the True Airspeed (85 knots) is under the grommet. (See Fig. 39)

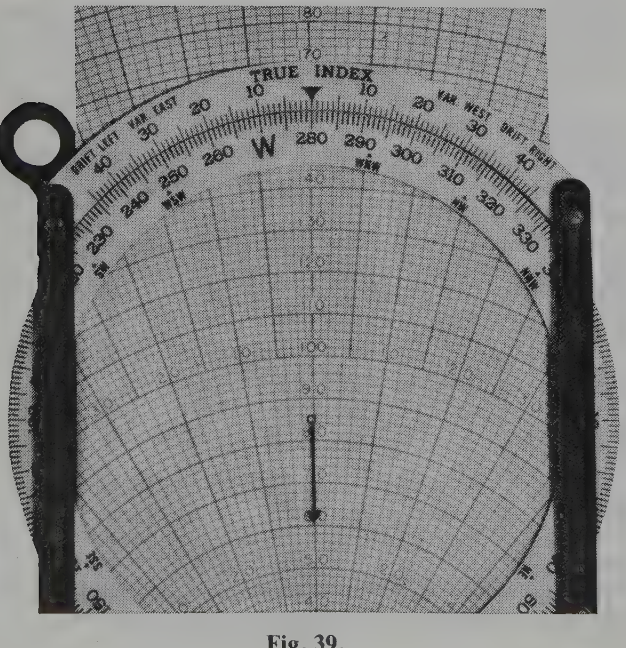


Fig. 39.

5. Rotate the compass rose to set the True Track, (332°) at the True Head Index.

6. The wind vector arrow indicates 16° of drift right. (See Fig. 40)

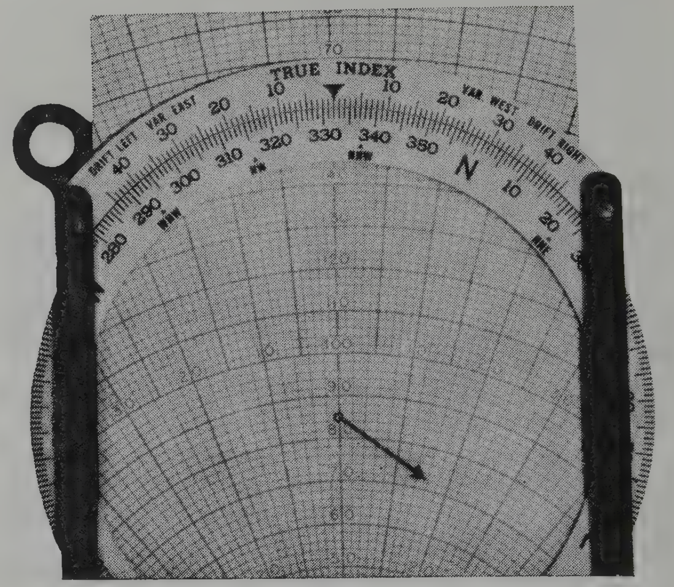


Fig. 40.

7. Rotate the compass rose to set the True Track, (332°) opposite 16° Drift Right on the Drift Scale.

8. It will be noted that the wind vector arrow has moved to indicate 12° of drift right. It is necessary for the drift on the drift scale to indicate the same number of degrees as does the wind vector arrow. Certain adjustments are necessary to realize this equalization.

9. Therefore, rotate the compass rose slowly moving the True Track, (332°) back towards 12° Drift Right until the degrees Drift Right agrees with the degrees Drift Right indicated by the wind vector arrow. In this problem, this occurs when the True Track (332°) is set opposite 13° Drift Right.

10. Read the True Heading (319°) under the True Head Index.

11. Read the groundspeed (67 kts) on the speed circle at the arrow at the end of the wind vector line. (See Fig. 4l)

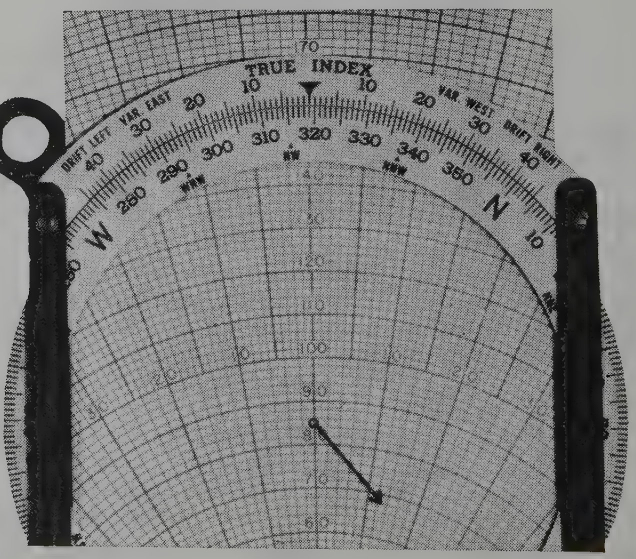


Fig. 4l.

Alternate Solution By Computer

Your ground school instructor may prefer an alternate method in which you plot the wind **up** the centre line.

1. Set the wind direction, 280°, on the compass rose opposite the True Head index.

2. From the grommet, draw a line 25 knots **up** the centre line (the wind speed).

3. Set the True Track, 332°, at the True Head.

4. Set the tail of the wind line on the 85-knot Speed Line (the airspeed).

5. Read the groundspeed at the grommet — 67 knots.

6. From the Drift Line passing through the tail of the wind line, measure the **Wind Correction Angle** (angle between Heading and Track). Heading is 13° to the *left* of track. Wind correction angle 13° left.

7. Read the True Heading on the Left Drift Scale at the 13° mark — 319°.

These are two methods for solving the same problem by the Flight Computer. Both methods get the same result. Whichever method, you decide to use **Stick To It.**

PROBLEM 2

Suppose that it is desired to leave Niagara Falls and arrive at Toronto Island Airport at a specified time, in other words, to make good a given groundspeed.

The True Track is 332°. The wind is 280° (True) at 25 kts. The groundspeed required is 67 kts. What is the Heading to steer and the Airspeed?

Solution By Plotting

1. Draw A-C (Fig. 38) to represent the Wind and Windspeed.

2. Draw A-D to represent the Track and Groundspeed.

3. Join C and D. C-D is the Heading to steer — 319° and Airspeed — 85 kts.

Solution By Computer

1. Set Wind Direction (280°) under the True Head Index.

2. Draw a wind vector down from the grommet to the proper length to represent 25 knots, and draw an arrow at the end of the line.

3. Rotate the compass rose until the True Track, (332°) is opposite the True Head Index.

4. Move the slide until the arrow at the end of the wind vector line is on the proper speed line (67 kts).

5. Read the approximate drift (17° Right) at the arrow of the wind vector line.

6. Rotate the compass rose in the direction of the wind vector (in this problem, to the right) until the True Track is opposite 17° Right on the Drift Scale. Readjust the slide until the arrow of the wind vector line is again on the 67 knot speed line.

7. Check the drift. It is now about 12°. Rotate the compass rose back towards 12° on the drift right scale until the degrees on the drift scale equal the degrees of drift indicated by the wind vector arrow, at the same time keeping the wind vector arrow on the 67 knot speed line.

8. Read the True Heading (319°) under the True Head Index.

9. Read the True Airspeed (85 kts) on the speed line under the grommet.

PROBLEM 3.

To find the Wind and Windspeed, knowing the Heading and Airspeed and the Track and Groundspeed.

A Nav-Air Tutor is flying on a heading 033° Magnetic, at a cruising speed of 95 kts. It is making good a Track 048° Mag. and a groundspeed of 100 kts. What is the Wind and Windspeed?

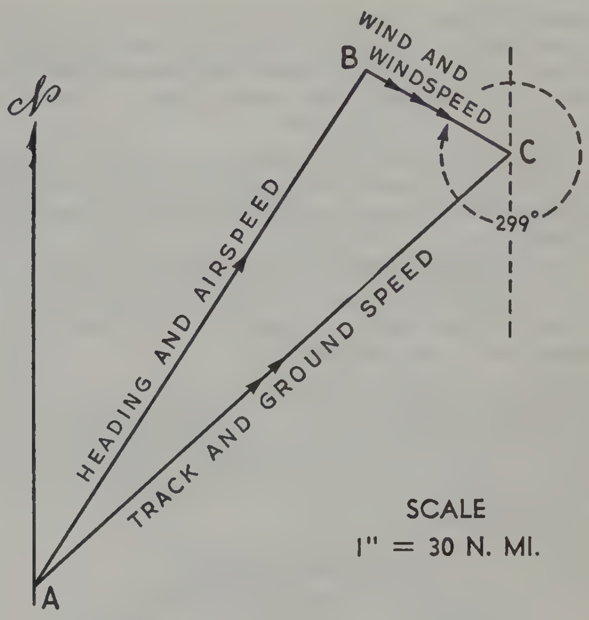


Fig. 42.

Solution By Plotting

1. From A draw A-B, 033°, 95 kts. to scale, to represent the Heading and Airspeed (Fig. 42).

2. From A draw A-C, 048°, 100 kts. to scale to represent the Track and Groundspeed.

3. Join B-C.

Then the angle B-C makes with the Meridian (transferred) represents the Wind and Windspeed — from 299° Mag. at 26 kts.

The direction of the wind is always from the Heading to the Track.

Solution By Computer

1. Set the Heading (033°M) opposite the True Head Index.

2. Move the slide until the true airspeed (95 knots) speed line is under the grommet.

3. Compare the figures given for heading and track. The difference between heading and track is the drift. When track is greater than heading, drift is right. When track is less than heading, drift is left. In this problem, track is greater than heading and the drift is, therefore, 15° right.

4. Locate the drift line 15° to the right of the grommet.

5. Along this line, locate the speed line for 100 knots. Make a cross at the intersection of the 15° drift line and the 100 knot speed line.

6. Connect the cross with the grommet. This line is the wind vector.

7. Rotate the compass rose until the wind vector points down along the centre line. Read the wind direction (299°) at the True Head Index and the wind speed (26 knots) as the length of the wind vector line.

THE FLIGHT COMPUTER: CIRCULAR SLIDE RULE SIDE

Calculation in navigation is much simplified by the use of a computer, such as the Dalton Dead Reckoning Computer. The Wind Drift side of the Computer has already been discussed. The other side is a Circular Slide Rule.

The Dalton Computer, illustrated in Fig. 43, is practically identical to the many other types of navigational computers that are available. The Circular Slide Rule is logarithmic in principle and, therefore, it can be used to solve any problem of multiplication, division or proportion. From a navigational point of view, however, its value lies in the rapid solution of time, speed, distance and conversion problems.

Note that the Slide Rule consists of three scales. The outer scale is fixed to the computer. The two inner scales are printed together on a disc that may be rotated to any position opposite the outer scale.

The outer scale represent miles, gallons, true airspeed and corrected altitude. The inner scale represents time in minutes, calibrated airspeed and calibrated altitude. The third scale represents time in hours and minutes.

The figures on a slide rule may represent any proportion or multiple of ten. "10" on the outer scale may therefore represent 1, 10, or 100. "45" on the inner scale may represent 4.5, 45, or 450. In the latter case, if 450 represented 450 minutes, the equivalent hours and minutes could be read directly on the third scale as 7 hrs. 30 min.

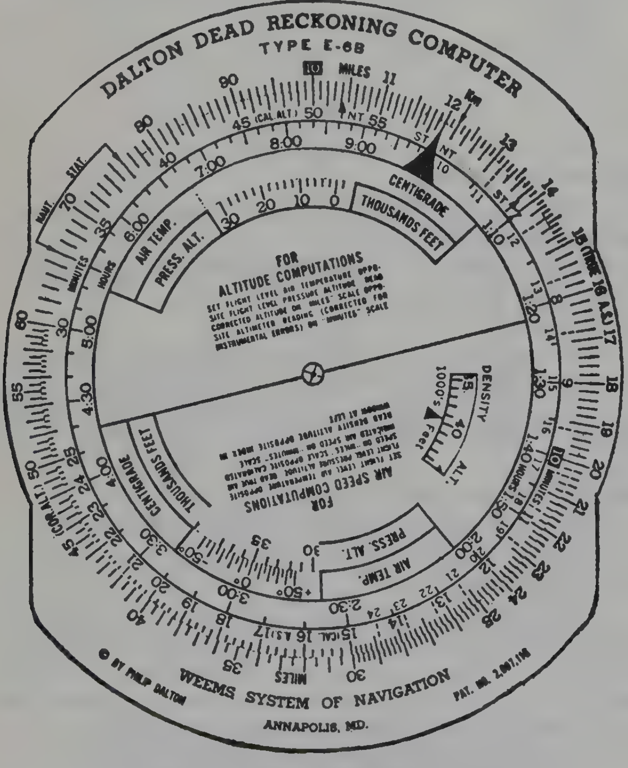


Fig. 43. The Circular Slide Rule.

SOLVING PROBLEMS WITH THE CIRCULAR SLIDE RULE

TIME, SPEED AND DISTANCE

For time, speed and distance problems, the outer scale represents miles, the inner scale minutes and the third scale hours and minutes. In such problems, there are three variables: time, distance and speed. Two must be known to solve a problem.

To find the distance when the groundspeed (140 kts) and the time (48 mins) are known, set "140" on the outer scale opposite "60" on the inner scale. Read the distance on the outer (miles) scale opposite "48" on the inner (minutes) scale. The distance is 112 n. miles.

To find the elapsed time when the groundspeed (146 kts) and the distance (100 n. miles) are known, set "146" on the outer scale opposite "60" on the inner scale. Read the time on the inner (minutes) scale opposite "100" (10) on the outer (miles) scale. The elapsed time is 41 minutes.

To find the groundspeed when the distance (30 n. miles) and the time (15.5 minutes) are known, set "30" on the outer scale opposite "15.5" on the inner scale. Read the groundspeed on the outer (miles) scale opposite "60" on the inner (minutes) scale. The groundspeed is 116 knots.

FUEL CONSUMPTION

To solve problems relating to fuel consumption, the outer scale may be used to represent gallons and the inner scale to represent time.

To find endurance when the consumption in gallons per hour (16) and the quantity of fuel (72 gallons) are known, set "16" on the outer scale opposite "60" on the inner scale. Opposite "72" on the outer scale, read the endurance on the inner scale. The answer is 270 minutes, or 4 hours and 30 minutes.

To find fuel consumption when the amount of fuel consumed (12 gallons) in a given time (2 hr. 21 min.) is known, set "12" on the outer scale opposite "2 hr. 21 min." on the third scale. Read the fuel consumption in gallons on the outer scale opposite "60" on the inner scale. The fuel consumption is 5.1 gallons per hour.

CONVERSION

Nautical to Statute Miles. The "Naut" and "Stat." Mile Indexes will be found on the outer scale (towards the left hand side in Fig. 43). Set any figure on the inner scale representing nautical miles opposite the Nautical Mile Index and read the corresponding statute miles on the inner scale opposite the Stat. Mile Index. Or, to convert statute miles to nautical miles, set the figure representing statute miles opposite the Statute Miles Index and read the corresponding nautical miles opposite the Naut. Mile Index.

Imperial to U.S. Gallons. Mark 10 (for 1) on the inner scale as the Imperial Gallons Index, and 12 (for 1.2) as the U.S. Gallons Index. Set any figure on the outer scale — 7.2 Imp. Gals. for example — opposite 10 on the inner scale. The figure on the outer scale that is opposite 12 will be the corresponding U.S. Gals. Answer: 8.65 U.S. Gals.

Celsius to Fahrenheit. This conversion cannot be worked on the Slide Rule. Practically all navigation computers, however, have a Celsius to Fahrenheit Conversion Table printed on them. In the Dalton E6B illustrated, the table is printed on the other side of the computer.

ALTITUDE CORRECTION

The pressure altimeter used in airplanes is a relatively accurate instrument. However, it is calibrated to indicate the true altitude in ICAO Standard Atmosphere conditions (i.e. perfectly dry air with a MSL pressure of 29.92 inches of mercury and a MSL temperature of 15°C and standard lapse rate). With the subscale that is incorporated into the pressure altimeter, the pilot can correct for changes in atmospheric pressure, but he cannot correct for temperatures varying from that of Standard Atmosphere. Therefore, the altitude indication of an altimeter is always in error.

To calculate true altitude using a computer, it is necessary to know the pressure altitude. Alter the subscale on the sensitive altimeter to read 29.92 and read the pressure altitude. Set the pressure altitude against the outside air temperature in the computer window marked "For Altitude Computations". Opposite the indicated altitude on the calibrated altitude scale (inner scale), read the true altitude on the corrected altitude scale (outer scale). For example, Indicated Altitude is 17,500 feet. Pressure Altitude (with altimeter setting of 29.92) is 18,000 feet. Temperature is —5°C. True Altitude is 18,600 feet.

AIRSPEED CORRECTION

The airspeed indicator is also subject to error as a result of temperature and the decreasing density of the air with altitude.

To find true airspeed, set the flight level air temperature opposite the flight level pressure altitude in the computer window marked "For Airspeed Computations". Pressure altitude is obtained by setting the reading 29.92 on the subscale of the sensitive altimeter. Read the true airspeed on the outer scale opposite the figure representing the indicated airspeed on the inner scale. For example: Pressure Altitude is 16,000 ft. Temperature is —10°C. An Indicated Airspeed of 200 knots is equivalent to a True Airspeed of 260 knots.

DENSITY ALTITUDE

The knowledge of the Density Altitude is of special importance in determining the performance of an airplane. At high altitude airports when the temperature is high, the available runway may be insufficient for the performance capabilities of a particular type of airplane.

To find Density Altitude, set the pressure altitude opposite the air temperature in the computer window marked "For Airspeed Computations". For example: Pressure Altitude is 6000 feet. Temperature is 20°C. The Density Altitude, read in the little window marked "Density Alt" is 8000 feet.

NAVIGATION PROBLEMS

FUEL HOURS

Many navigation problems are based on Fuel Hours combined with the Wind Drift Problems which we have already studied. The fundamental factors required for the solution of all Fuel Hour problems are:

1. The Fuel Consumption.
2. The Quantity of Fuel available in the tanks.
3. The Groundspeed of the airplane.

The **Time** the airplane can fly on its available fuel (less reserve) can be found from 1 and 2.

The **Distance** the airplane can fly in that time can be found from 3.

Problem 1.

A pilot starts to fly from Winnipeg, Manitoba to Regina, Saskatchewan. The track is 277° True and the distance is 288 nautical miles. The plane has a cruising speed of 120 knots. Fuel capacity is 45 gallons. Fuel consumption is 11 gallons per hour. Unable to get a forecast wind, the pilot assumes no wind. At the end of 28 minutes, he is over Portage La Prairie. With this wind, the pilot is anxious to know if he has sufficient fuel to reach Regina without drawing on his 45 min. reserve.

Solution: Fuel capacity is 45 gallons. Fuel consumption is 11 gal/hr. Using the Circular Slide Rule, the fuel hours on board are calculated to be 246 minutes, or 4 hours 6 minutes. Deduct 45 minutes for reserve, and the safe fuel hours available are 3 hours 21 minutes.

Portage La Prairie is 42 n. miles from Winnipeg. The airplane has covered this distance in 28 minutes. Its groundspeed therefore is 90 knots.

At a groundspeed of 90 knots, the flight from Winnipeg to Regina (288 nautical miles) will take 3 hours 11 minutes which is sufficient to reach Regina without drawing on the airplane's 45 min. reserve.

Problem 2.

A pilot wishes to fly from Goshen, Indiana to Fargo, N.D., via Joliet, Illinois, along the airways. He wishes to know the farthest point he can reach along the route before refuelling. A schematic diagram of the route is shown in Fig. 44.

The airplane has a cruising speed (true) of 100 knots. Its fuel capacity is 25 gals., and its consumption 5-1/2 gals/hr. The wind is from the north at 30 kts.

Solution: The airplane's endurance, found by using the Circular Slide Rule, is 272 minutes. Deduct 45 minutes for reserve and the safe endurance is 227 minutes.

The track from Goshen to Joliet is 270°T and the distance is 107 nautical miles (n.m.). By plotting or by wind drift computer, the groundspeed on the leg to Joliet is found to be 95 knots. At this groundspeed, the elapsed time to Joliet will be 73 minutes. Safe fuel hours remaining are 154 minutes (227 min. less 73 min.).

The track from Joliet towards Fargo is approximately 316°T. Using the same wind, by plotting or by wind drift computer, the groundspeed on this leg will be found to be 77 knots. At this groundspeed, in 154 minutes the plane will travel 202 n.m. The airport safely nearest this distance along the track is La Crosse (197 n.m.).

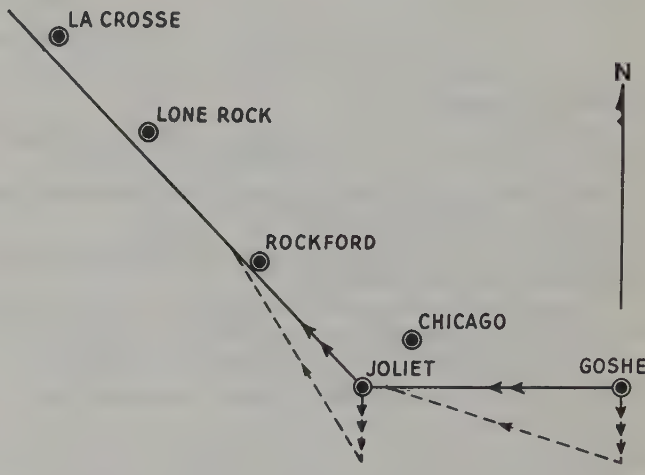


Fig. 44.

RADIUS OF ACTION

The Radius of Action (R/A) is the greatest distance an airplane can fly along a certain course, under given conditions of wind, true airspeed, fuel consumption and a given quantity of fuel and return to the same base.

The problem is to find the R/A of a Piper Tri-Pacer along a Track, 093° True. Wind from 020°T. at 20 kts. Cruising speed 110 kts. Fuel endurance 5 hours. (i.e., 4 hrs. 15 min. plus reserve).

Solution by Plotting

1. From A (Fig. 45) draw A-B 93° (to represent the Track Out) and extend it back to some point C (to represent the Track Home).
2. From A, draw A-D at 020° to the Meridian (the wind line is always drawn downwind), 20 knots to scale.
3. With centre D, and radius 110 knots (the airspeed) describe arcs cutting A-B and A-C at E and F. Join D-E and D-F.

Then A-E = Groundspeed Out = 102 kts.
A-F = Groundspeed Home = 114 kts.

The safe fuel hours = 5 hours, less 45 min. reserve, which is 4 hrs. 15 min., or 4.25 hrs.

The Radius of Action is found by the following formula:

$$F \times \frac{(O \times H)}{(O + H)} = R/A$$

Where: F = Safe fuel hours.
O = Groundspeed out.
H = Groundspeed home.

$$\text{Then } F \times \frac{(O \times H)}{(O + H)} = 4.25 \times \frac{102 \times 114}{102 + 114} = 229 \text{ n. miles}$$

The Heading to steer out is 083°T. (D-E)
The Heading to steer home is 283° T (D-F)
The Time to Turn is found by the formula:

$$\frac{R/A}{O} = \frac{229}{102} = 2.24 \text{ hrs., or 2 hr. 14 min.}$$

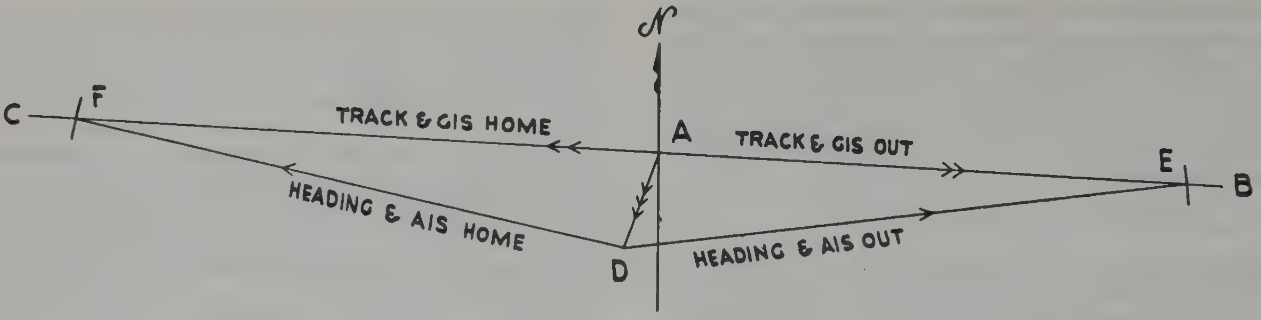


Fig. 45. Radius of Action.

Solution By Computer

The solution of this type of problem, requiring the use of both sides of the computer, is broken down into two steps:

Wind-vector solution, which computes the true heading and groundspeed outbound and inbound; and

Radius-of-action proportion, which computes time to turn and the radius-of-action distance.

1. Set up wind triangle as in Wind Drift Problem I, using W/V of 020° at 20 knots, True Track of 093°T and cruising airspeed of 110 knots, to determine heading and groundspeed.

2. Read True Heading Out (083°) at the True Head Index.

3. Read Groundspeed Out (102 knots) at the arrow at the end of the wind vector line.

4. The drift is 10° Right.

5. To determine the True Heading for the return flight, rotate the compass rose until the reciprocal of the True Track outbound (i.e. 273°) is opposite 10° Drift Left on the Drift Scale. (To find the reciprocal of a True Track, add or subtract 180 degrees.) Note: On a reciprocal heading, the drift will be opposite in direction. Check the drift indicated by the wind vector arrow to determine that it also indicates 10° Drift Left and that no juggling is necessary. Keep the TAS set at 110 knots.

6. Read True Heading Home (283°) at the True Head Index.

7. Read Groundspeed Home (114 knots) at the arrow at the end of the wind vector line.

This completes the solution of groundspeed and true heading, outbound and inbound. The remainder of the problem is solved on the Circular Slide Rule part of the Computer.

8. Opposite the safe endurance time of the airplane (4 hrs. 15 mins.) on the inner scale (A in Fig. 46), set the sum of the groundspeed out and the groundspeed home (which is 216 knots) on the outer scale.

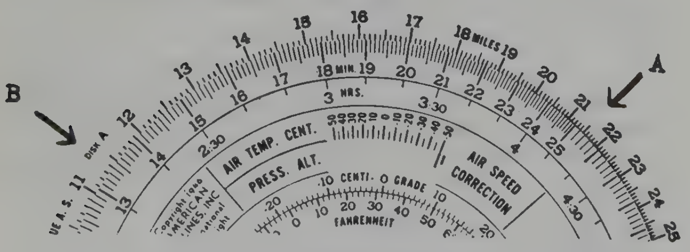


Fig. 46.

9. Opposite the groundspeed home (114 knots) on the outer scale, read the time until time-to-turn in minutes on the inner scale (134 mins., or 2 hrs. 14 mins.). See B on Fig . 46.

Therefore on the outbound flight, you can fly for 2 hrs. and 14 mins. before you must turn back.

10. To determine the distance flown in this time, place the groundspeed out (102 knots) on the outer scale opposite the pointer on the inner scale. Opposite the time (134 minutes) allowed for the outbound flight, on the inner scale, read the distance on the outer scale, 229 nautical miles.

229 nautical miles is the Radius of Action.

POINT OF NO RETURN

On long flights over oceans, jungles, or featureless country such as the Arctic, there is a point somewhere along the track beyond which, if trouble occurs, there is insufficient fuel remaining to return to base and it is mandatory to go on. This is called the **Point Of No Return.** If the trouble is due to weather or some other cause which doesn't impair the performance of the airplane, this point is the **Time To Turn** which was determined in the Radius of Action problem above.

CRITICAL POINT

An airplane forced to turn back might be in difficulties (such as the loss of an engine in a multi-engine airplane) and be forced to fly at less than its normal cruising speed. In an emergency such as this there is little time for calculation. The reduced airspeed of the airplane in distress should therefore be anticipated in advance. A good figure to assume is 60% of normal cruise speed. The **Critical Point** is a position somewhere along the route *between two air bases* from which it is equally **quick** to fly to either base. Based on a reduced airspeed, a predetermined Critical Point will enable a pilot in distress to instantly make up his mind whether it is advisable to turn back or to continue on.

An airplane cruising at a True Airspeed of 250 kts. is flying from A to B along a track of 095°T, a distance of 1800 n. miles. The average wind over the route is estimated to be from 030°T at 30 kts. The reduced airspeed is assumed to be 60% of the normal cruise speed, or 150 kts.

Solution By Plotting

1. Draw A-B, the intended Track, 095°, 1800 n. miles to any convenient scale (Fig. 47).

2. From some point X draw XW, 030°, 30 knots (the wind down-wind). For convenience, a much larger scale can be used to plot this portion of the problem than that used to draw the line A-B.

3. With centre W and radius 150 n. miles (the Reduced Airspeed) describe arcs cutting X-B and X-A at O and H. Join W-O and W-H.

W-O is the Heading to steer Out, 085°T.

W-H is the Heading to steer Home, 285°T.

X-O is the Reduced Groundspeed Out, 135 kts.

X-H is the Reduced Groundspeed Home, 159 kts.

4. Draw any line A-Y inclined to A-B and mark off A-C equal to X-H, and C-D equal to X-O.

5. Join D to B. Through C draw a line parallel to D-B cutting A-B at P.

P is the Critical Point. It is 973 n. miles from A.

6. With centre W and radius 250 kts. (the True Airspeed) describe an arc cutting A-B (produced) at Q. Join W-Q.

W-Q is the Actual Groundspeed Out, 236 kts.

The Time to Turn is the time to fly 973 n. miles at the Actual Groundspeed Out, i.e.: 973 ÷ 236 = 4.12 hr. (4 hr. 7 min.)

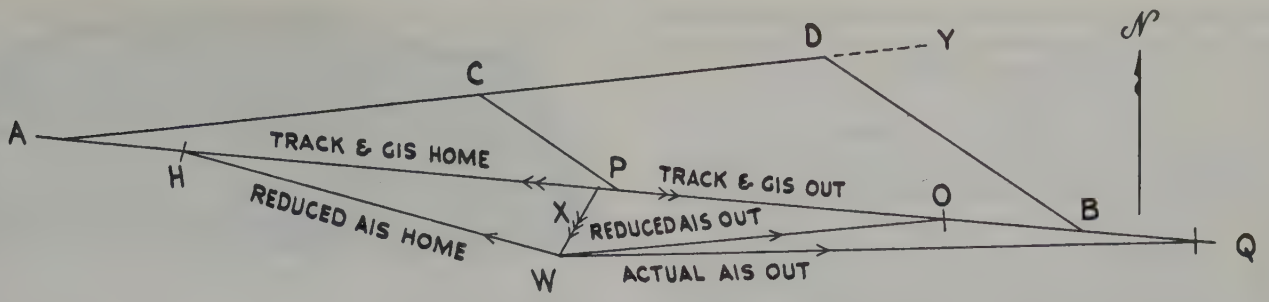


Fig. 47. Critical Point.

Solution by Computer

1. Set up wind triangle as in Wind Drift Problem I, using the True Airspeed of 250 knots.

2. Read groundspeed of 236 knots at the arrow at the end of the wind vector line.

3. Set up wind triangle as in Wind Drift Problem I, using the reduced airspeed of 150 knots.

4. Read True Heading Out (085°) at the True Head Index.

5. Read Reduced Groundspeed Out (135 knots) at the arrow at the end of the wind vector line.

6. The drift is 10° Right.

7. To determine the inbound heading and groundspeed, rotate the compass rose to set the reciprocal course (095° + 180° = 275 °) opposite 10° Drift Left on the Drift Scale.

8. Read True Heading Home (285°) at the True Head Index.

9. Read Reduced Groundspeed Home (159 knots) at the arrow at the end of the wind vector line.

On the Circular Slide Rule side of the Computer:

10. Place the reduced groundspeed home on the outer scale opposite the reduced groundspeed out on the inner scale. See A on Fig. 48.

11. Search the slide rule for two numbers such that their sum will equal the total distance between the two points. One figure will be the distance from the base to the critical point, and the other will be the distance from the critical point to the destination. As to which figure is the one to choose as the critical point, visualize the effect of the wind.

In this case, we find that 973 on the outer scale corresponds with 827 on the inner scale, their sum equalling 1800 nautical miles which is the total distance. The wind is a tail wind for the flight home and therefore the choice for the critical point is 973 nautical miles. See B on Fig. 48.

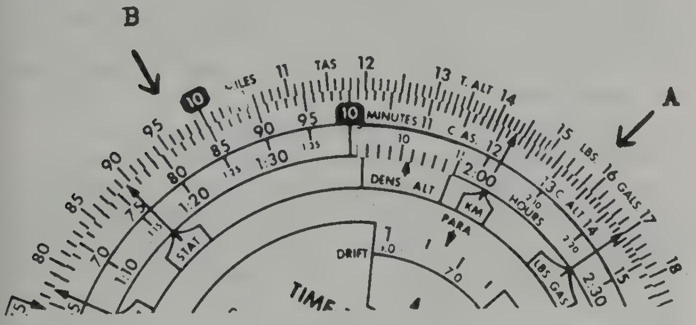


Fig. 48.

12. The time to the critical point is found by dividing the distance found in Step 11 (out to the critical point) by the normal groundspeed out (found in Step 2 to be 236 knots). On the computer, set the pointer opposite 236 and read the time opposite 973. Answer is 247 mins, or 4 hrs. 7 mins.

The critical point, therefore, is 973 nautical miles from base, and the time to turn is 4 hours and 7 minutes.

The critical point can also be determined by the following formula.

$$P = \frac{D \times H}{O + H} = \frac{1800 \times 159}{135 + 159} = 973 \text{ n. miles.}$$

The Time to Turn is found by:

$$\frac{P}{G} = \frac{973}{236} = 4.12 \text{ hrs. (4 hr. 7 min.)}$$

In the above: P is the Critical Point.
D is the Total Distance to Fly.
O is the Reduced Groundspeed Out.
H is the Reduced Groundspeed Home.
G is the Actual Groundspeed Out.

CALCULATING RECIPROCALS

By reciprocal is meant the reverse, or opposite, of a given direction such as a Heading, Course, Track or Bearing.

e.g. Track	187°
Reciprocal	007°

The reciprocal is found by adding or subtracting 180— **adding** if the direction is 180 degrees, or less— **subtracting** if it is greater than 180 degrees.

However, determining the reciprocal of a Heading is not so simple. Since Wind Drift allowance is the vital consideration in determining the Heading to make good a particular track and since the wind will have quite a different effect in making good a reciprocal track, it can readily be seen that adding or subtracting 180 from the Heading is not the method to calculate the reciprocal Heading. The approximate Heading to steer to make good the reciprocal track may be calculated by the following method:

Calculate the reciprocal of the heading out, and double the wind correction angle the opposite way.

If the wind correction angle out has been 5° to port, to double it the opposite way, you **add** 10° (to starboard) to the reciprocal of the heading out to obtain the heading home. (Any correction applied to the right, or starboard, or clockwise, is **added.**)

If the wind correction angle out has been 5° to starboard, you **subtract** 10° (to port) from the reciprocal of the heading out to obtain the heading home. (Any correction applied to the left, or port, or anticlockwise, is **subtracted.**)

Problem

A pilot is flying a Compass Heading of 122°. He runs into bad icing conditions and decides to turn for home.

A glance at his Flight Plan tells him that his True Heading is 117° and his Track (True) is 122°.

The Reciprocal of his Heading is 297° (117° + 180° = 297°).

He is therefore, steering 5° to Port of his Track (to correct for a drift of 5° to Starboard).

To double the wind correction angle the opposite way, he would now steer 10° to Starboard of 297°.

His True Heading for home would therefore be 297° + 10° = 307°.

Using the same variation he had on his heading out and the deviation applicable to his new heading, he can now easily determine the Compass Heading to steer for home.

CALCULATING THE CLIMB OR LET-DOWN

An airplane's airspeed is reduced during its climb and sometimes during a portion of its descent from cruising altitude. Its groundspeed is similarly affected. In planning a cross-country flight, the "climb and descent vectors" — that is, the portions of the flight required for climb and let-down — should each be calculated as separate time and distance problems, using the average wind and average airspeed temperature correction during the climb or let-down. The three separate segments of the flight should then be added to find the total time. i.e.: Time during climb + Time at cruising altitude + Time during let-down — Total Elapsed Time. This may prove too time-consuming for the average pilot-navigator. A general rule that you may find helpful is: Compute your flying time for the total distance using your true airspeed and the wind at cruising altitude. Then add 1 minute per 1000 ft. of cruising altitude *above the elevation of the airport at point of take-off* to allow for time lost in climb and let-down. e.g.: Cruising altitude, 7000 ft. less elevation of airport, 1000 ft. = 6000 ft. Add 1 min/1000 ft. which is 6 minutes to your total time to allow for climb and let-down.

Commercial pilot examination requirements include the solution of climb and let-down problems.

Problem

An airplane is flying towards its home airport where the elevation is 1267 ft. MSL (above Mean Sea Level). It is flying at an altitude of 10,000 ft. MSL, and with a groundspeed of 165 kts. The pilot wishes to descend at a rate of 400 ft. per min. and arrive over the airport at 1000 ft. above the ground, maintaining a constant groundspeed of 120 kts. How many minutes before his estimated time of arrival over the airport should he start his descent?

The airport has a field elevation of 1267 ft. MSL. Therefore 1000 ft. *above ground* will be 1267 + 1000 = 2267 ft. *Above Sea Level.*

The pilot's descent will be 10,000 — 2267 = 7733 ft. At a rate of 400 ft./min., the time required to let-down will be 7733 ÷ 400 = 19.3 min.

Problem

After landing, the pilot referred to above decides to take off again and climb to a cruising altitude of 9,000 ft. MSL, at a rate of 300 ft./min. In the climb, he makes good a groundspeed of 165 kts. How far, in nautical miles, will he be from the airport when he reaches cruising altitude?

The airport has an elevation of 1267 ft. MSL. The climb to cruising altitude will therefore be 9,000 — 1267 = 7733 ft. At a rate of 300 ft./min., this will take him 7733 ÷ 300 = 25.7 min. At a groundspeed of 165 kts., he will travel 165 ÷ 60 × 25.7 = 70.6 n. miles.

The D/R computer can also be used for calculating let-down. Referring to the first problem above in which an airplane flying at 10,000 MSL is approaching an airport whose elevation is 1267 MSL. Descending at approximately 400 ft/min and maintaining a constant groundspeed of 120 knots, how many miles out should the pilot begin his descent in order to arrive over the airport at circuit height? Find the number of feet to descend (10,000 — 2267 = 7733) in hundreds on the outer scale. Set under it the rate of descent in hundreds of feet on the hour scale (400 ft/min would be 4.00 hours) (See Fig. 49 "A"). On the minutes scale, find the groundspeed in tens of miles (120 knots would be 12) and read the number of miles directly on the miles scale (38.5 miles) (Fig. 49 "B").

The same setting can be used to determine what rate of descent will bring the airplane to circuit height above the airport, if the pilot begins his descent 38.5 miles out from the airport.

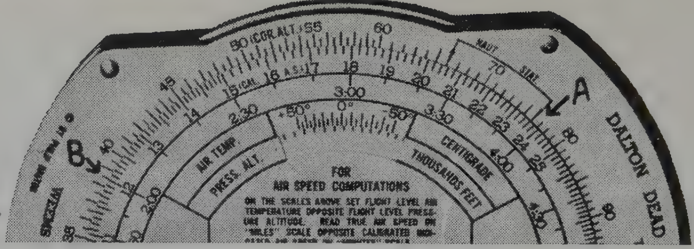


Fig. 49.

CALCULATING CLIMB RESTRICTION PROBLEMS

At some airports, especially in congested areas, ATC may issue a departure clearance requiring a minimum climb rate per nautical mile. You will have to decide quickly if you are capable of this requirement. The following is a rapid method for solving this problem.

Problem

ATC has given a clearence . . . "This departure requires a minimum climb rate of 400 feet per mile until . . . . . ." Your planned climb speed gives a 120 knot groundspeed. What climb rate in feet per minute must you meet to comply with the clearance?

Set your climb groundspeed of 120 knots on the miles scale adjacent to 60 minutes on the minute scale. Find the given climb requirement of 400 feet per nautical mile on the minutes scale. On the miles scale read 800. You will be required to maintain a climb rate of 800 feet per minute. If your airplane will do at least this considering your weight and power available, then accept the clearance and go.

You must use nautical miles in computing this problem.

FINDING THE WIND VELOCITY IN THE AIR

Of all the various methods devised for finding the wind velocity in the air, the only two which have any practical value from a pilot-navigator's point of view is the Track and Groundspeed Method and Two Drift Method — since one does not involve any deviation of the airplane from its track, and the other is so easily accomplished when flying over areas where the Track and Groundspeed method cannot be used.

Track and Groundspeed Method

A Cessna 170 on a navigation exercise passes checkpoint A at 10:10 and arrives at checkpoint B at 10:27. The cruising speed is 120 mph. The airplane is flying on a heading of 120°T.

A line joining A and B on the map represents the actual track made good (107°T).

The distance between A and B is 36 miles.

Therefore, the groundspeed is 127 mph.

Knowing the Heading and Airspeed (120°T—120 mph) and the Track and Groundspeed (107°T—127 mph) the wind velocity can now be found by plotting or computer as detailed in Wind Drift Problem 3. Ans. Wind from 218° at 29 mph.

Drift Method

A steady heading is flown at a constant airspeed and the drift noted. The heading is then altered, if possible by not less than 50°, and the drift again noted. If time permits, the heading should again be altered, either at least another 50° in the same direction or back 100°, and a third drift noted.

It will be seen that very little time is lost by use of this method. If the heading alterations are made first to one side of the track and then to the other, and provided that approximately the same time intervals are flown on each leg, the airplane will be very close to the original track when turned on to the original heading again.

This third drift angle is not essential, but it is desirable as a check. The wind velocity can then be found by combining this information on a mechanical computer or by plotting on the map or chart.

THE AIR POSITION

No pilot can ever become hopelessly lost if he knows his Air Position. **The Air Position** of an airplane at any time is its imaginary position, assuming that there has been no wind since it left the ground. It will be obvious then that if the Air Position is known, the worst a pilot can be in error as regards **Ground Position** is a distance and direction equal to the speed and direction of the wind for the length of time he has been flying.

The Air Position is recorded by navigators on what is known as an **Air Plot.** This is the laying down on a map or chart of the **heading and airspeed** of the airplane during the entire time it is in the air.

While it is not possible for the Pilot-Navigator to keep an Air Plot and fly the airplane at the same time, it is of the **utmost importance** that he should keep a mental picture of his Air Position in his mind. By jotting down in his log the exact time that each change in compass heading is made — should his whereabouts become uncertain in poor visibility — he can run back over his log and construct a rough diagram of his Air Position in his mind. Thus, when some landmark does appear in view below, he has a good general idea of the area on his map to search in order to identify it.

Note: The keeping of a "Log" does not necessarily mean writing endless volumes of figures down on a comprehensive form. The few simple notations required by the Pilot-Navigator, such as time of departure, heading flown, times over points along the route, groundspeeds calculated, etc., can be jotted down on the border of the map if a note book doesn't happen to be handy.

Position Lines

Suppose you are standing on a street in Toronto down which you can see the Legislature rising above the end of the avenue of trees. You consult your street guide and identify the street as University Avenue. You know you are somewhere on University Avenue, but you have no means of knowing exactly where. However, you note that you are standing at the crossing of a street named Dundas Street. Now you locate the intersection of University Avenue and Dundas Street on the map and you have fixed your exact position.

Position lines are obtained by observing the bearing of two or more objects and are plotted on a map or chart to fix the position of the observer in the same way that the intersection of University Avenue and Dundas Street was used to locate a position above.

Problem

A Canso Amphibian is patrolling out to sea off the Atlantic Coast. The Port of St. Hilda is sighted and is found to bear 018° True. If the bearing of St. Hilda is 018° from the flying boat, then the direction of the flying boat is the reciprocal (opposite) of 018° or 198° from St. Hilda. A line is drawn on the chart from St. Hilda 198° (A-B in Fig. 50.). This is a **Position Line** somewhere on which line it is known the airplane must be at a particular time. A position line is identified by arrowheads at either end and the time at which it was obtained is clearly marked, in this case 10.15 hrs.

Suppose that at the same time, the Beach Head light ship was found to bear 052°. A second position line (C-D) may be drawn 232° from the light ship on the chart.

Where the two position lines intersect gives the position of the airplane at 10.15 hrs. This is called a **Fix.**

It will be seen that in Fig. 50 a third position line (E-F) has been plotted from a bearing on Dog Island of 338° (reciprocal 158°). The purpose of including this third position line in the figure is to show that where three or more position lines are used, they may not always intersect at a common point. Note that E-F does not pass through the intersection of A-B and C-D, but forms a small triangle, or "cocked hat". This is due to small errors in taking the bearings, or in plotting. If the "cocked hat" is small, the fix is taken to be the dot (•) shown in the centre of the triangle. If the "cocked hat" is excessively large, no reliance can be placed on the fix.

When plotting a fix by two or more position lines the angle between the position lines should not be less than 30° and preferably about 60°.

Upon obtaining a fix and marking it on a map or chart, it is possible to calculate the latitude and longitude of the airplane at the time the bearing was taken. This information is important in relaying position reports over water and uninhabited areas to Air Traffic Control authorities.

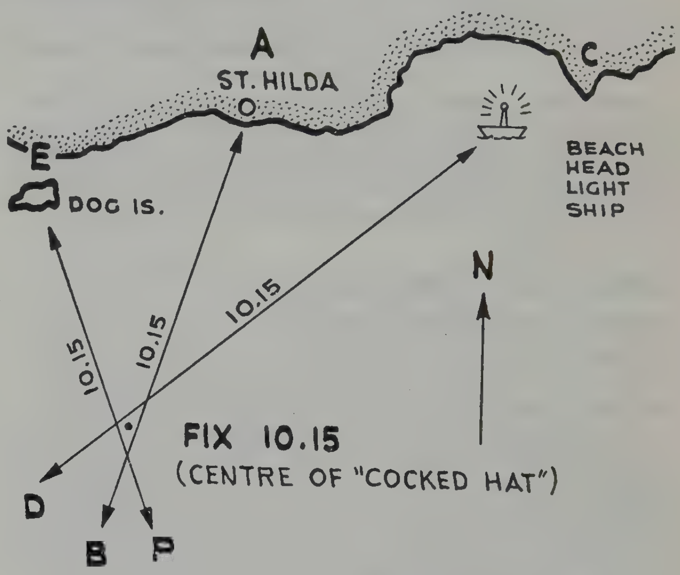


Fig. 50. Fix By "Cocked Hat", Three Position Lines.

There are many methods of obtaining position lines — by Transit, by Direction Finding Radio, by observations of Celestial Bodies, etc. It is of the **utmost importance** therefore that the simple methods detailed above, explaining their use in fixing the position of an airplane, should be thoroughly understood by the elementary student in order to enable him later on to tackle the more advanced problems he will encounter in Radio and Celestial Navigation.

ELECTRONIC FLIGHT CALCULATOR

Electronic Flight Calculators are now making their appearance on the market and may one day make Wind Drift Computers and Circular Slide Rules obsolete.

Fig. 51. Electronic Flight Calculator.

These calculators, similar to the one illustrated in Fig. 51, are preprogrammed to solve navigational problems, such as true heading, groundspeed, time en route, distance, wind drift, fuel requirements, true airspeed, density altitude, rate of climb and descent, conversions (n. miles to s. miles, C° to F°, etc.), weight and balance, etc., in a matter of seconds.

Flight calculators made by different manufacturers will each operate slightly differently. Usually it is necessary first to select a function key that corresponds with the problem to be solved and then punch in the known information to solve the problem.

THE PILOT NAVIGATOR

A pilot flying alone obviously cannot use such instruments as a plotting board, bearing compass, drift sight, etc. However, a good knowledge of the principles of navigation will enable him with practice to make very accurate mental calculations en route.

With good average visibility, favorable weather, and a good map of the territory to be flown over, successful navigation depends on little more than the ability to read a map in general terms.

With low visibility, or over comparatively featureless country, however, steering an accurate heading by compass becomes of primary importance. The route and groundspeed must be checked frequently, and accurate map reading is essential in order that the exact position of the airplane may be checked at frequent intervals.

"TWO-POINT" METHOD OF FLYING A VISUAL RANGE.

When it is not possible to obtain a wind before departure, or time does not permit plotting it, a satisfactory method of determing the heading to steer is that known as flying a visual range.

Two points are selected along the Track about 5 or 10 miles apart. The pilot, having gained the height it is intended to maintain throughout the flight, flies a heading by map reading that will pass over these two points. His compass will then indicate the heading to steer for the balance of the flight. Other points along the route may be selected subsequently and a series of ranges flown. This method is particularly useful if it is necessary to alter heading during a flight to a destination other than that originally intended.

GROUNDSPEED CHECK

By noting the distance between check points along your route and keeping track of the time, the groundspeed may be found. e.g.: Distance from Reykjavik to Hlodufell Mountain (Fig. 52)—50 s.mi. Time—20 min. Therefore, the groundspeed = 150 mph. Now, knowing the distance to your next check point (say the Pjorsa River, which crosses the Track at approximately the right hand edge of Fig. 52)—47 s.mi., you can estimate your time of arrival over this point. e.g.: At a ground speed of 150 mph, time to fly 47 miles = 19 min. Time over Hlodufell was, say, 10:05. Therefore, the ETA over Pjorsa River should be 10:24.

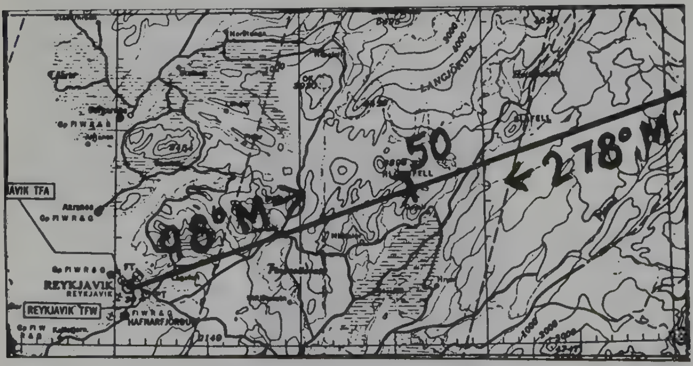


Fig. 52.

THE "ONE-IN-SIXTY" RULE

An error in the Track of one degree will cause an error in position of about one mile in a distance of 60 miles.

A pilot on a cross-country flight who has got off his Track will be able to estimate the distance he is off in miles quite easily but it is very difficult to know how many degrees it is necessary to alter heading by compass to correct the error.

Suppose an airplane is 2 miles off its track after travelling 30 miles. The error in the track will be roughly 4°. Therefore the correction to the compass heading will be 4° to correct the error. This will put the airplane on a track *parallel* to the required track but 2 miles from it. Suppose the airplane is 60 miles from its destination. An additional 2° correction to heading will gradually close the track. Therefore a total correction of 6° will bring the airplane in to its destination.

PRESSURE PATTERN FLYING

Since winds circulate *clockwise* around high pressure areas and *anti-clockwise* around low pressure areas, it is often advantageous to plan the flight around the pressure systems in order to take advantage of the most favorable winds. Such a diversion is known as a **Minimal Flight Path** or **Least Time Track.** This is the shortest *time* between two points, rather than the shortest *distance*. The selection, and use, of a Least Time Track is one aspect of what is known as **Pressure Pattern Navigation.**

High and low pressure areas, with the winds associated with them, are clearly indicated on weather maps. For flight below 3,000 ft. this information is best obtained from the Surface Weather Map. Above this altitude, use the Upper Level Charts. In flying the pressure pattern, there is a certain amount of calculated risk regarding the possibility of wind and pressure changes which may occur during your flight. However, the forecaster will brief you regarding the possibility of any in-flight changes that might seriously affect your flight plan.

Transocean navigators have evolved techniques which enable them to determine and trace the changing movements of pressure systems while enroute and to calculate drift position lines from comparative readings of the radar and pressure altimeters. Pressure Pattern "techniques" have been practised by birds for centuries. Flocks have been known to wait for days until the circulation provided a good tailwind for their winter migration south.

Aeronautical Facilities . . .

Across the continent, there is an intricate system of aeronautical facilities designed to facilitate the efficient movement of air traffic. It won't be long before a new pilot with his new license will be anxious to take off from his home and very familiar airport to visit some of the hundreds of other airports throughout the country. In order not to be intimidated by new, different and bigger airports, an understanding of the basics of airport design is an essential part of a pilot's training. To reach those other airports, he will have to cope with the intricacies of controlled and uncontrolled airspace, airways, control zones, cruising altitudes, etc., etc. This chapter is designed to introduce the pilot to aerodromes, to the airspace system and to the regulations and procedures of flight in the Canadian airspace.

AERODROMES

The many aerodromes across the continent vary widely in the facilities they offer to the itinerant pilot. The large metropolitan airports with several runways, complicated patterns of taxiways and sophisticated lighting systems seem very complex in comparison to the single strip sod runway that constitutes the aerodrome of many small communities throughout the country. There are, however, certain standard features that apply to every aerodrome, no matter how large or how small.

The term, **Aerodrome**, is defined as any area of land or water designed for the arrival, departure and movement of aircraft.

The term, **Airport**, is defined as any aerodrome for which a license has been issued by the Minister of Transport.

RUNWAY NUMBERING

Airport runways are numbered for the purpose and convenience of identification. The number a runway is assigned corresponds to its magnetic bearing, rounded off to the nearest 10°. For convenience, the last zero is omitted. Thus Runway 09 would be the runway which runs from west to east (090° magnetic). Since runway numbers are taken to the nearest 10° magnetic, a runway which lies 018° magnetic would be considered as being 020° magnetic and would be numbered 02.

The runway number is displayed at the approach end of each runway. A single runway would, therefore, have different numbers at each of its two ends. These numbers would be 180° apart, or reciprocals of each other. For example, runway 09 above would be numbered 27 at the other end, and runway 02 would be 20.

While airports throughout most of Canada are assigned numbers based on their magnetic bearings, those in the Northern Domestic Airspace are assigned numbers based on true bearings. (The Northern Domestic Airspace, defined in Section **The Canadian Airspace System**, comprises the northern and Arctic areas of Canada.) In this northern area, compass indications are unreliable because of the nearness of the North Magnetic Pole and therefore true bearings are considered more reliable for runway numbering purposes.

At larger aerodromes, there are sometimes two or more runways parallel to each other. The letter "R" below the number of a runway indicates that it is the right of a pair of parallel runways. An "L" indicates the left runway. The letters are always assigned as viewed from the direction of approach. Triple runways are designated "L", "C" or "R" and would be called, for example, "three six left", "three six centre" and "three six right".

RUNWAY MARKINGS

The perimeters of unpaved runways are required to be delineated with frangible, weatherproof markers that are clearly visible both on the ground and from the air. These markers, that may be either pyramid shaped or cone shaped, are evenly spaced at intervals of not more than 300 feet along the sides of the runway. Additional markers are placed at the four corners of the runway at right angles to the centre line.

At licensed aerodromes, these markers are painted in alternate stripes of international orange and white; at unlicensed aerodromes, they are international orange only.

Evergreen trees about 4 or 5 feet high are sometimes used to mark the perimeters of snow covered landing strips.

PAVED RUNWAYS

In addition to the number that is painted in large white figures at the approach end of the runway, lines are usually painted down the centre of the runway to help the pilot align his airplane during landings and take-offs.

Sometimes the entire paved portion of the runway is not usable as the landing area. In this case, the **threshold** of the usable portion is displaced and its position is marked by a line across the runway with arrowheads pointing to it. Centre line arrows also point to the threshold line. A **displaced threshold** usually is made necessary because of obstacles at the end of the runway that require additional clearance during the approach.

Sometimes, special threshold markings are included as part of the runway marking scheme. These consist of 2 sets of four bars parallel to the sides of the runway. They serve to indicate that a non-precision approach facility such as a VOR serves the runway and that the runway can be used for landing under instrument conditions.

Runways for which there are precision approach facilities, such as an ILS, have additional landing zone markings at 500 foot intervals down the length of the runway. Touchdown zone stripes, consisting of 2 sets of 3 parallel white stripes are painted at a distance of 500 feet from the threshold of the runway; fixed distance markers, 2 thick parallel stripes, indicate 1000 feet; two sets of double stripes indicate 1500 feet and 2000 feet; and two sets of single stripes indicate 2500 feet and 3000 feet of runway.

TAXIWAYS

Taxiways are an important part of the aerodrome facilities. They enable airplanes to move to and from runways without interfering with traffic taking off and landing.

Yellow lines are usually painted down the centre of taxiways. A broad yellow line across it indicates the end of the taxiway where an airplane must "hold short" until ready for take-off. At a controlled airport, the airplane must hold at this position until receiving clearance from the tower to enter the runway itself for take-off.

An airplane may not cross an active runway at a controlled airport without first obtaining clearance to do so. The broad yellow line indicates the position at which it must hold until clearance is received.

At the large airports where there are quite a number of taxiways, they are assigned letters for identification (e.g. "A") and would be referred to as Taxiway Alfa.

AERODROME MARKINGS

Certain ground markings indicate the status of some aerodromes and pilots are required to comply with these markings.

A large cross, usually white, displayed at each end of a runway (or any maneuvring area or taxiway of an airport) indicates that that runway (or area) is unserviceable. (Fig. 1). For night operations any unserviceable portion of a runway is closed off by placing red lights at right angles to the centreline across both ends of the unserviceable area. In addition, the runway lights for the unserviceable area should be turned off.

A horizontal red square panel with a yellow diagonal "X" indicates that landings are prohibited and that the prohibition may extend for some time. (Fig 1).

A horizontal red square with one yellow diagonal line indicates that special precautions should be observed during the approach and landing because of the bad state of the maneuvring area. (Fig. 1).

A horizontal white dumb-bell indicates that airplanes are required to land, take-off and taxi on runways and taxiways only. (Fig. 1).

A horizontal landing "T" painted either white or orange, indicates the direction to be used by airplanes for landing or taking off (i.e. along the shaft towards the cross arm of the "T"). The landing "T" is either illuminated or outlined by white lights at night. (Fig. 1).

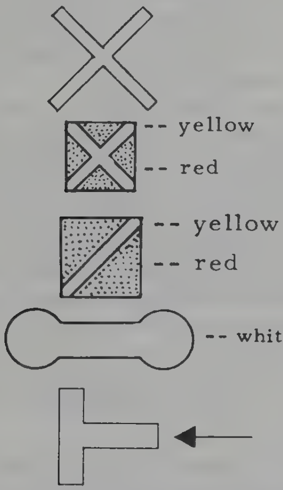


Fig. 1. Aerodrome Markings.

If an unserviceable portion of any maneuvring area or taxiway is small enough that it can be bypassed by an airplane with safety, red flags are used to outline the area of unserviceability. At night, the area is marked by steady red lights. Sometimes, in the interest of safety, one or more flashing red lights may be used as well.

WIND INDICATORS

The runway in use is determined by the wind direction since airplanes, during landing and take-off, operate most efficiently and safely by flying as directly into the wind as possible. All airports are therefore required to display a device that indicates which way the wind is blowing. There are several types of wind indicators, as depicted in Fig. 2.

The **Windsock** or **Wind Cone**, (on the left in Fig. 2), the old reliable good samaritan to homecoming airmen since World War I, is the traditional symbol of flying fields the world over. The wind always blows in the big end and out the small end. The velocity of the wind is indicated by the amount of extension of the windsock. A fluttering cone indicates gusty conditions. At night, the windsock is illuminated.

The Tetrahedron, or Wind T, is designed like an arrow whose small end points into the wind.

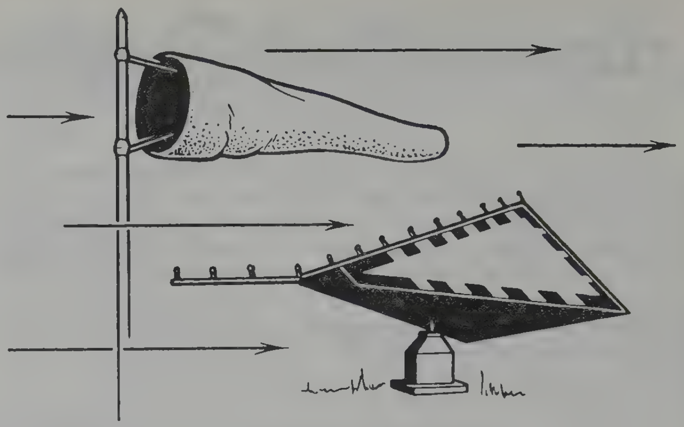


Fig. 2. Wind Direction Indicators.

Wind indicators are, by order of the Air Navigation Orders, coloured international orange and white at licensed airports and solidly orange at unlicensed aerodromes.

AERODROME LIGHTING

For night operations, **landing and take off areas** (i.e. runways) are indicated by two parallel lines of white lights that are visible at least 2 miles in all directions.

The **runway threshold** is indicated by green lights. These lights when viewed from the back are red and indicate the end of the runway for traffic landing and taking off when the other end of the runway is active.

The edges of **taxiways** are marked by blue lights. Sometimes green lights are installed down the centre line of taxiways.

An **airport beacon** helps a pilot to locate an airport amidst all the other confusing ground lights of a community. The beacon is a white light that rotates at a constant speed producing highly visible light flashes at regular intervals of about 10 seconds. The airport beacon operates continuously during night time hours. When it operates during daylight hours, it indicates that the weather at the aerodrome is below VFR limits.

Obstruction lights are used to mark tall buildings and towers that might be flight hazards. These may be red lights that are either steady or flashing or they may be flashing white strobe lights.

APPROACH LIGHTS

Many airports have an installation of approach lights that extends from the centreline of the runway back along the approach path. They help the pilot to align his airplane with the runway. There are various types of approach light systems. Most are high intensity lights. Some are steady; some flash in sequence towards the threshold.

Visual Approach Slope Indicator System (VASIS)

The Visual Approach Slope Indicator System has been installed at many airports to help a pilot maintain a correct glide path on his approach to the runway.

The system consists of a set of upwind and a set of downwind lights. Each light unit projects a beam of white light in its upper part and a red light in its lower part. The light units are so arranged that when a pilot of an airplane is approaching the runway on the proper approach slope, the downwind lights will appear white and the upwind lights will appear red. (Fig. 3).

If the airplane is below the proper approach slope, both sets of lights will be red. If it is above the approach slope, both sets of lights will be white. (Fig. 3).

The lights are so arranged that the approach slope angle is about 2.5° to 3° and if the pilot maintains this approach slope, he will land between the two sets of lights.

In certain atmospheric conditions, the white lights sometimes appear yellowish, orange or brown. The red lights, however, are not affected and the principle of colour differentiation is still applicable.

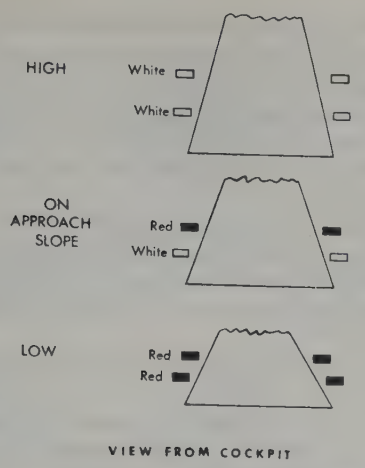


Fig. 3. VASIS Approach Lights.

At some airports used by the very large jet airplanes, a 3 bar VASIS has been adopted to accomodate the greater eye to wheel heights of these airplanes. The third bar is positioned farther down the runway and is, in effect, an extra upwind set of lights. Pilots of small airplanes may ignore the most distant set of lights during an approach to a runway equipped with the 3 bar VASIS.

A variation of the VASIS called the T-VASIS is installed at a few airports. It eliminates the requirement to discriminate colour except in a dangerously low approach when the lights will appear red. The T-VASIS installation consists of 10 lights on each side of the runway; 3 lights in a row parallel to the runway, 4 lights in a bar at right angles to the runway and another 3 lights in a line beyond the bar. On the proper approach slope, only the bar of 4 lights is visible. On a too high approach, the 3 upwind lights also are visible producing an inverted T. On a too low approach, the 3 lights downwind of the bar combine with the bar lights to show an upright T.

AERODROME TRAFFIC PROCEDURES

A pattern for traffic movement has been established for use at all aerodromes. It is called a **Traffic Circuit** (in the U.S., it is called a Traffic Pattern) and it expedites and separates airplanes using the same aerodrome.

It is the responsibility of every pilot, for safety and efficiency, to learn and follow the proper traffic procedures when coming in to land at an aerodrome.

The following definitions apply to portions of the traffic circuit:

The **Upwind Side** is the area on the opposite side of the landing runway from the downwind leg. Approach should be made into this area at or above circuit height.

The **Circuit Joining Crosswind** is a corridor, lying within the airspace between the centre of the landing runway and its upwind end, linking the upwind side and the downwind leg.

The **Downwind Leg** is a flight path, opposite to the direction of landing, which is parallel to and at a sufficient distance from the landing runway to permit a standard rate-one turn to the base leg.

The **Base Leg** is a flight path at right angles to the direction of landing and sufficiently downwind of the approach end of the landing runway to permit at least a ¼ mile final approach leg after completion of a standard rate-one turn to final approach.

The **Final Approach Leg** is a flight path in the direction of landing, commencing at least ¼ mile from the runway threshold, wherein an airplane is in line with the landing runway and descending towards the runway threshold.

THE TRAFFIC CIRCUIT AT UNCONTROLLED AIRPORTS

There are two ways to enter the uncontrolled traffic circuit. You should approach the traffic circuit from the upwind side of the runway, enter crosswind at circuit height and join the circuit on the downwind leg. You may also approach straight in to the downwind leg and join the circuit at circuit altitude in level flight where the downwind leg and crosswind intersect.

When approaching a strange airport, you should enter the airport zone throttled back to slow speed and letting down in a gradual descent. Never dive into the area from a height or out of clouds.

Circuit height should be reached before entering the traffic circuit.

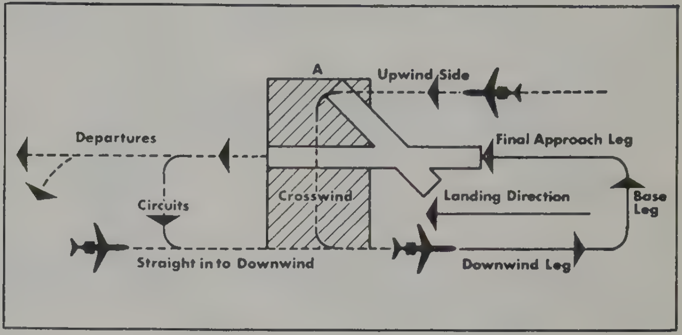


Fig. 4. The Traffic Circuit at Uncontrolled Airports.

In joining the circuit, always take care to avoid "cutting off" other airplanes and overtaking the airplane ahead of you when approaching to land.

If it is necessary to cross the airport prior to joining the circuit (to study an unfamiliar airport, to determine the runway in use, or for any other reason), the cross over should be done well above circuit height (at 2000 feet AGL or more) and descent to circuit altitude should be made on the upwind side.

Circuit altitude is established as 1000 feet above the elevation of the aerodrome unless otherwise specified because of particular circumstances at a certain location. Except when the cloud and ceiling situation prevents it, all aircraft in the traffic circuit must maintain the 1000 foot circuit altitude on the crosswind and downwind legs.

Landing should be made on or parallel to the runway most nearly aligned into wind. However, you as pilot have the final authority and responsibility for the safe operation of your airplane and you may select another runway in the interest of safety if you choose.

Left hand circuits are normally in use at most airports in Canada. At a few, right hand circuits have been designated and in that case, the reverse of the traffic flow pictured in Fig. 4. would apply.

If you are flying circuits, you should, after each take-off, reach circuit altitude before joining the downwind leg.

In taking-off and departing the circuit, you should climb straight ahead on the runway heading until clear of the traffic circuit. Any turn while operating in the vicinity of the aerodrome should be made to the left (except of course when a right hand circuit is in effect).

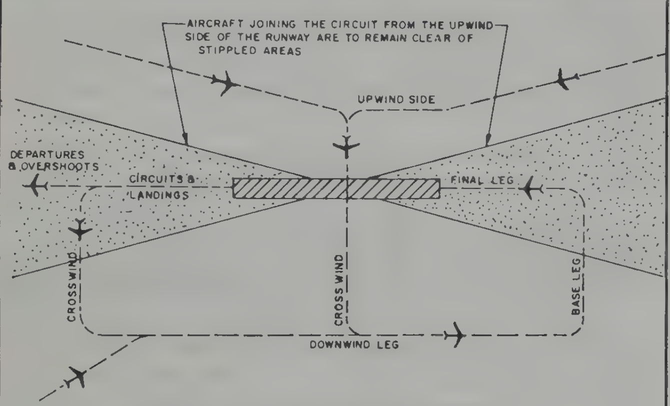
If your airplane is radio equipped, it is a good practice to monitor the appropriate radio (122.2 MHz) or unicom (122.8 MHz) frequency at all times when in the vicinity of the airport, transmit your own position reports and broadcast your intentions.

After landing, clear the runway as quickly as possible by turning off at the nearest taxiway. If it is necessary to taxi back along the runway in use, turn left 90° and watch for airplanes landing before proceeding to taxi. All turns made to clear the runway should be made to the left. It is standard practice for a pilot landing behind an airplane that has just touched down to pass to the right as he overtakes the other airplane.

THE TRAFFIC CIRCUIT AT CONTROLLED AIRPORTS

The traffic circuit at a controlled airport is not dissimilar from that at an uncontrolled airport. It consists also of a downwind leg, a base leg and a final approach leg. (Fig. 5) The principal difference is that you must establish communication with the control tower.

Prior to entering the positive control zone (which surrounds all controlled airports), you, as pilot, must call the tower on the appropriate frequency, give your identification and position and request landing instructions. The airport controller will advise the runway in use, wind direction and speed, altimeter setting and any other pertinent information and then will clear you to enter the circuit. **"Cleared to the Circuit"** authorizes you to join the circuit on the downwind leg at circuit height. If because of your position in relation to the runway in use, it is necessary to proceed crosswind prior to joining the circuit on the downwind leg, do so as indicated in Fig. 5, approaching the active runway from the upwind side at a point midway between each end of the runway staying clear of the approach and departure paths of the active runway.


AIRCRAFT JOINING THE CIRCUIT FROM THE UPWIND SIDE OF THE RUNWAY ARE TO REMAIN CLEAR OF STIPPLED AREAS
UPWIND SIDE
DEPARTURES & OVERSHOOTS
CIRCUITS & LANDINGS
FINAL LEG
CROSSWIND
CROSS WIND
BASE LEG
DOWNWIND LEG

Note - where a right hand circuit is established the opposite of this diagram is applicable.

Fig. 5. Traffic Circuit at Controlled Airports.

The airport controller may clear you to a straight in approach and in this instance, you may join the traffic circuit on the final approach leg without having executed any other portion of the circuit.

Once established in the traffic circuit, you should advise the tower of your position (e.g. **"FRLT is downwind"**). The tower will then give you your landing instructions. For example:

Tower: **Piper FRLT you are number one.** Or,

Tower: **Piper FRLT you are number two. Follow Cessna 185 now on base leg.**

You must have landing clearance prior to landing. Normally, the controller will clear you to land as you turn onto final. If this does not happen, it is your responsibility as pilot to request landing clearance in sufficient time to accomodate the operating characteristics of your airplane. If you do not receive landing clearance, you must pull up and make another circuit. Even after landing clearance is given, the tower may advise you to pull up and go around again if the situation on the runway becomes unsafe for landing.

If after landing clearance is accepted, the situation is such that you, as pilot, feel that there is a hazard to the safe operation of your flight, you should advise ATC of your intentions and go around again. If, for example, the cross wind component is too much for the capabilities of your airplane, you may request another runway that is more into wind if one exists. Always advise ATC of your intentions.

After landing you should clear the runway without delay by continuing forward to the nearest available taxi strip or turn off point. If you have landed beyond a turn off point, proceed to the end of the runway, turn off and wait for permission to taxi back to an intersection. Do not turn and taxi back against the direction of landing traffic unless instructed to do so by the tower.

Landing NORDO (without radio) at a Controlled Airport

Aircraft without radio (NORDO) are not permitted to land at most large controlled airports served by the scheduled air carriers. However, where they are permitted to operate (less busy controlled airports), they are directed by visual signals. You, as pilot, must be alert for the light signals from the tower letting you know what to do.

To join the traffic circuit, you must do so from the upwind side of the runway, join crosswind at circuit height as in Fig. 5 and turn onto the downwind leg. You must conform to the size and speed of the circuit and maintain adequate separation from airplanes ahead of you.

Before turning on final, you must check for any airplanes on a straight in approach.

The tower will give you landing clearance on final approach by means of a light signal. If landing clearance is not given, you must pull up and go around again.

The following are authorized visual signals:

Steady Green Light — Clear to land.

Steady Red Light or Red Flare — Do not land — continue in circuit. Avoid making sharp turns, climbing or diving after you receive this signal.

Flashing Green Light — Recall signal. Return for landing (usually to recall an airplane which has taken off or has been previously waved off with a red light). This will be followed by a steady green light when the approach path and landing area is clear.

Alternating Red and Green Light (U.S.) — Danger — Be on alert. This signal may be used to warn you of such hazards as danger of collision, obstructions, soft field, ice on runways, mechanical failure of your undercarriage, etc. The danger signal is not a prohibitive signal and will be followed by a red or green light as circumstances warrant.

Flashing Red Light — Airport unsafe. Do not land.

Red Pyrotechnical Light — The firing of a red pyrotechnical light, whether by day or night, and notwithstanding any previous instruction, means "Do not land for the time being".

By day, acknowledge all light signals from the tower by distinct rocking of the airplane; at night, by a single flash of the landing light.

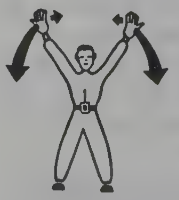
When cleared to land by a green light signal, come in on a straight glide or power approach for a distance of not less than 3000 feet. Do not S-turn. Continue to watch the Tower on final approach for further signals.

If your airplane is equipped with receiver only (RONLY), it is your responsibility to advise the airport controller of this fact, preferably by filing a Flight Plan. Otherwise he will instruct you by means of visual signals.

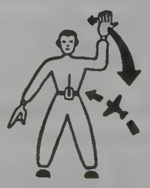
The procedures by which you join the circuit are the same as for NORDO aircraft.

The controller may request you to acknowledge his transmissions in a specified manner (i.e. rocking the airplane in flight).

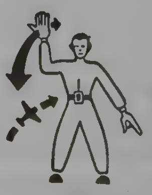
GROUND CONTROL SIGNALS TO AIRPLANES



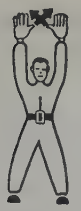
STRAIGHT AHEAD
Both hands beckoning "onwards".



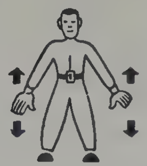
TURN TO YOUR LEFT
Right hand down. Left arm beckoning "on". Speed of hand movement indicates rate of turn.



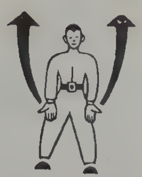
TURN TO YOUR RIGHT
Left hand down. Right arm beckoning "on". Speed of hand indicates rate of turn.



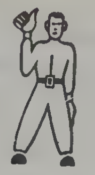
STOP
Hands wagging above head. Speed of hand movement indicates urgency of stop.



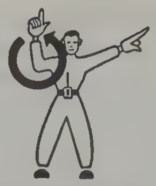
SLOW DOWN
Hands moved up and down with palms towards ground.



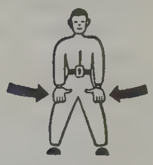
STRAIGHT BACK
Both hands waving "backwards".



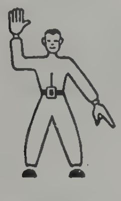
ALL CLEAR
Right fist clenched and raised. Thumb up.



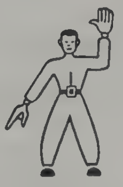
START ENGINE
Circular motion with right hand. Left hand pointing to engine.



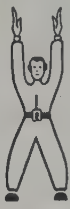
INSERT CHOCKS
Hands down palms facing inwards. Arms swinging inwards.



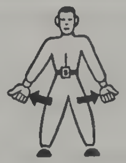
TURNS WHILE BACKING
For tail to right. Left hand down. Right hand waved up and down.



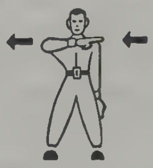
TURNS WHILE BACKING
For tail to left. Right hand down. Left hand waving up and down.



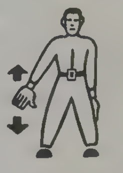
THIS BAY
Hands above head with palms facing inwards.



CHOCKS AWAY
Hands down palms facing outwards. Arms swinging outwards.



CUT MOTORS
Hands moved across neck in "throat cutting" motion.



SLOW DOWN MOTOR(S)
Right or left hand waved up and down with palm towards ground. Hand used indicates whether right or left motor(s).

THE CANADIAN AIRSPACE SYSTEM

For the purposes of air traffic control, separation and control of airplanes flying by reference to instruments and by visual reference, national defence, search and rescue, etc., the Canadian airspace has been divided in a number of different ways. It is necessary for a pilot to have an understanding of these divisions.

DOMESTIC AIRSPACE

The Canadian Domestic Airspace is divided into two areas, the Northern Domestic Airspace and the Southern Domestic Airspace. The boundaries of these two divisions are illustrated in Fig. 6.

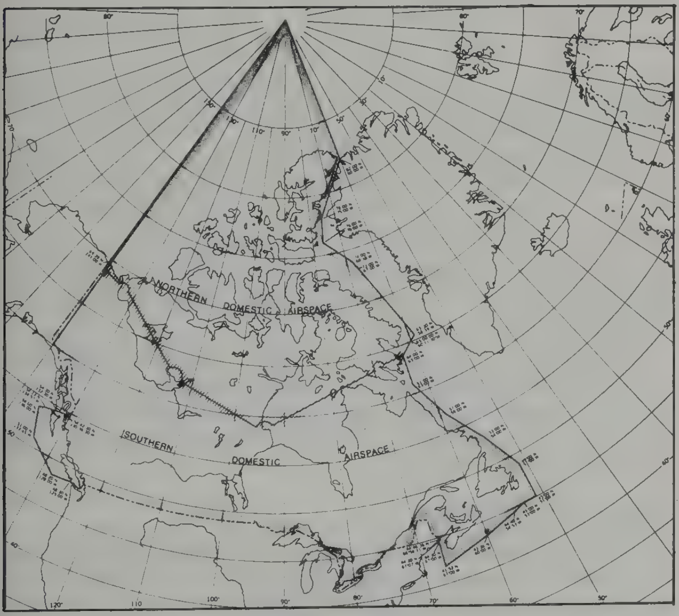


Fig. 6. Canadian Domestic Airspace.

NORTHERN DOMESTIC AIRSPACE

In close proximity to the North Magnetic Pole, the Earth's Lines of Force dip vertically towards the Pole, and the compass, which lies in a horizontal plane, loses its ability to point the way. There is, therefore, a large area of Canada in which magnetic compass readings are unreliable. This area was until recently known as the Area of Compass Unreliability and certain navigation procedures were recommended for operation in the area.

All aircraft operating in the Northern Domestic Airspace must fly at an altitude or flight level that is appropriate to their direction of flight as determined by **true** track calculations. Runway numbering is oriented to and surface winds are reported in degrees true. Aircraft operating at night or under IFR must be equipped with a gyroscopic direction indicator.

SOUTHERN DOMESTIC AIRSPACE

All aircraft in level cruising flight within the Southern Domestic Airspace must maintain an altitude or flight level that is appropriate to their direction of flight as determined by the **magnetic** track.

Airways, air routes, runway numbering are all based on magnetic headings. Surface winds are reported in magnetic degrees.

ALTIMETER REGIONS

Canadian airspace is divided, for purposes of meteorology, into an Altimeter Setting Region and a Standard Pressure Region. The geographic limits of these two regions are illustrated in Fig. 7.

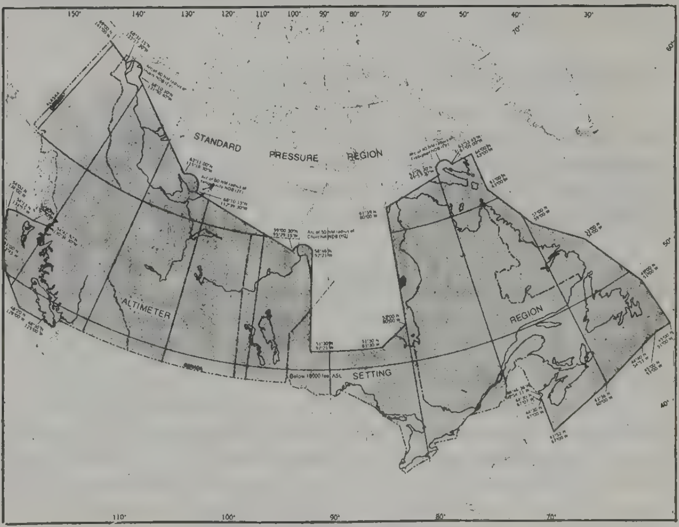


Fig. 7. Altimeter Regions.

THE ALTIMETER SETTING REGION

Within the Altimeter Setting Region, pilots must adjust their altimeters to the reported current altimeter setting of the nearest station along their route of flight, or where such stations are separated by more than 150 nautical miles, to the nearest station to the route of flight. Altimeter setting (QNH) is the setting made to an altimeter so it will indicate altitude ASL.

The Altimeter Setting Region includes the airspace up to 18,000 feet only.

THE STANDARD PRESSURE REGION

The Standard Pressure Region includes that area of Northern Canada depicted and so designated in Fig. 7 and also all airspace above 18,000 feet anywhere in Canada.

In the Standard Pressure Region, the altimeter is set to Standard Pressure (29.92'' Hg or 1013.2 mbs). For take off and climb, from an airport in this region, the altimeter should be set to the current altimeter setting (or the airport elevation) and reset to the Standard Pressure setting upon reaching the cruising altitude. For descent and landing, the current altimeter setting of the airport of intended landing should be set on the altimeter.

Altimeters must be reset after entering and before leaving the Standard Pressure Region, unless otherwise authorized by ATC. A transition level exists between the Altimeter Setting Region and the Standard Pressure Region. This is FL 180. When climbing (immediately after ascending through FL 180) change your altimeter from the current Altimeter Setting (QNH) to Standard Pressure. When letting down (immediately before descending through FL 180) change from Standard Pressure to the QNH Altimeter Setting.

FL 180 is not used for cruising in Canada.

IDENTIFICATION ZONES

The Defence Authorities of both Canada and the United States have established a number of Air Defence Identification Zones for the security control of air traffic. In Canada, they are known as CADIZ. It is imperative that pilots acquaint themselves with the locations and boundaries of these zones. They are denoted on aeronautical charts, radio facility charts, the **Canada Air Pilot** and in ANO Series V, No. 14.

In Canada, there are three types of Defence Identification Zones: Domestic CADIZ, Coastal CADIZ and DEWIZ (Distance Early Warning Identification Zone).

The Domestic CADIZ stretches across Canada from coast to coast through the central region of the country; the two coastal CADIZ lie off each coast and the DEWIZ extends across the roof of the North American Continent from Baffin Land on the east to Alaska on the west.

The procedures and regulations for flight within the CADIZ are more fully discussed in the Section **Air Traffic Rules and Procedures**, following.

SPARSELY SETTLED AREAS

Much of the geographical area of Canada is virgin land with very few settlements. Flight in this Sparsely Settled Area, the boundaries of which are defined in Fig. 8, requires special procedures. These procedures are described in the Section **Air Traffic Rules and Procedures**, following.

CONTROLLED AIRSPACE

Within controlled airspace some or all of the air traffic is controlled by ATC units. The various types of controlled airspace are discussed below.

The term **Control Area** refers to any controlled airspace. It has its base at a specified height above the ground or at ground level and extends upward indefinitely or to a defined altitude. For example, Airways, the Block Airspace, Control Zones, Northern, Arctic and Southern Control Areas, all of which are discussed below are Control Areas.

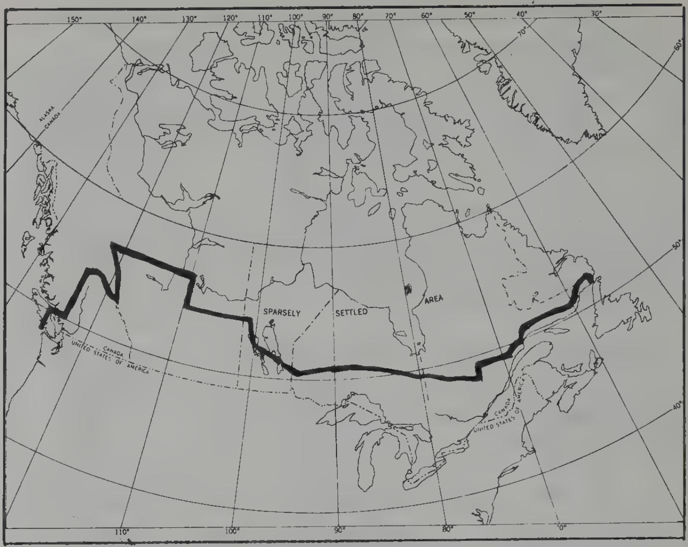


Fig. 8. Sparsely Settled Areas of Canada.

HIGH LEVEL AIRSPACE

High Level Airspace comprises all airspace within the Canadian Domestic Airspace 18,000 feet ASL and above. The High Level Airspace is divided into three regions.

The **Southern Control Area**. The boundaries of the Southern Control Area are the same as those of the Southern Domestic Airspace. Within the Southern Control Area (i.e. all airspace above 18,000 feet), all traffic is controlled.

The **Northern Control Area** extends from the northern limits of the Southern Control Area to a line approximately following the 72°N Parallel of Latitude. It comprises all airspace at and above FL 230. Within the Northern Control Area, all traffic is controlled.

The **Arctic Control Area** extends north from the boundary of the Northern Control Area to the North Pole. It comprises all airspace at and above FL 290. Within the Arctic Control Area, all traffic is controlled.

All flights, operating in these areas, use the Standard Pressure Region procedures in setting their altimeters. All flights must operate in accordance with Instrument Flight Rules and require an ATC clearance. As well, they are required to be equipped with a transponder having Mode A and 64 code capability.

In the Arctic Control Area and the Northern Control Area, there is airspace between 18,000 feet and FL 290 and FL 230 respectively which is considered High Level Airspace but in which there is both controlled and uncontrolled areas.

High Level Airways are prescribed tracks between specified radio aids to navigation in the High Level Airspace. Air traffic control is provided.

High Level Air Routes are prescribed tracks between specified navigation radio aids but along which Air Traffic Control Service is not provided. High Level Air Routes exist only in the airspace between 18,000 feet and the bases of the Arctic and Northern Control Areas.

LOW LEVEL AIRSPACE

Low Level Airspace comprises all airspace within the Canadian Domestic Airspace below 18,000 feet ASL. Not all airspace within this area is controlled. Boundaries of low level controlled airspace are indicated on Pilotage Charts by shaded lines, the solid edge of which defines the outer limits of the controlled area.

There are several different types of controlled areas within the Low Level Airspace.

Low Level Airways

Airways are routes between points along which aircraft can navigate by following NDB or VOR signals. These Airways are called "VOR" or "Victor Airways". They are followed by reference to "Courses" projected by chains of VHF Omnirange Stations located approximately 100 miles apart along the Airways. They are designated by the letter "V" and numbers (e.g. "V52").

Airways are 9 nautical miles wide. They have their base at 700 feet AGL and extend up to the base of the overlying high level airspace. Air traffic control service is provided.

When flying along Airways, fly down the centre line of the airway.

When crossing an Airway (other than at an intersection) cross it in level cruising flight and at an angle of not less than 45°.

Low Level Air Routes

Air Routes are similar to Airways in most respects except that along Air Routes air traffic control services are not available. Air Routes are not, therefore, within controlled airspace.

Air Routes extend between low/medium frequency or VOR navigation aids. They extend from the surface of the earth up to the high level airspace. They are also 9 nautical miles wide and are designated by colours and numbers (e.g. Amber Route 5, Blue Route 7).

Air Routes exist mainly in the northern areas of Canada.

Block Airspace

The Block Airspace comprises the airspace within designated airways between 9500 feet ASL and up to but not including 18,000 feet ASL east of Calgary (east of Longitude 114°W) and between 12,500 feet ASL and up to but not including 18,000 feet ASL west of Calgary (west of Longitude 114°W).

ATC exercises control of all air traffic within the Block Airspace. Therefore, to operate an aircraft in VFR conditions in Block Airspace, a pilot must have a clearance for such a flight from ATC and must have an IFR rating or have passed the Block Airspace Exam to obtain the special endorsement to his license which reads "Valid for Block Airspace".

The procedures and requirements for flight within the Block Airspace are more fully discussed in the Section **Air Traffic Rules and Procedures**, following.

Control Area Extensions

Control Area Extensions have been established around certain airports and radio navigation aids. Circular with a defined nautical mile radius, they extend upwards from 700 feet AGL to 18,000 feet ASL.

Aerodrome Traffic Zones

Aerodrome Traffic Zones have been established around some uncontrolled airports and unlicensed aerodromes. These aerodromes have no control tower facilities but do have approved instrument approach procedures. The zones have a radius of 5 nautical miles and extend from the surface of the ground up to 4000 feet AGL. Control Zone weather minima apply within these zones.

Control Zones

Control Zones are areas, usually 5 nautical miles in radius, extending upward from the surface of the earth to 4000 feet AGL. Within the Zone, air traffic is controlled from ATC facilities located at airports within the area. Control Zones sometimes have larger lateral dimensions and may be extended, when necessary, to include instrument approach and departure corridors. Control Zones are indicated on charts by coloured broken lines.

Positive Control Zones

Positive Control Zones are specific control areas so designated by the Minister and established around airports with ATC units. They begin at the surface of the earth but their upper limits vary from airport to airport.

Only aircraft with 2 way radio may operate within a Positive Control Zone and authorization from the appropriate ATC unit must be obtained prior to entering the Zone or before taking off from an airport within the Zone. The altimeter of the airplane must be set to the local altimeter setting. At all times within the Zone, a listening watch must be maintained on the ATC frequency. A NORDO aircraft may operate with special authorization if VFR conditions prevail during the duration of the flight.

Terminal Control Areas

A Terminal Control Area consists of airspace of defined dimensions extending upward from 700 feet above the surface of the earth. A Terminal Control Service provides air traffic control for arriving and departing IFR flights.

Terminal Radar Service Areas

Terminal Radar Service Areas (TRSA) are in operation around some of the major airports in Canada and will soon be implemented at others. Within this area, all flights, both VFR and IFR, are under the direct surveillance of Air Traffic Controllers.

The Terminal Radar Service Area (TRSA) is an airspace about 20 nautical miles in radius which surrounds a core Positive Control Zone. Unlike the Positive Control Zone which starts at ground level, the TRSA has its base 2000 feet above the ground. It extends up to the Block Airspace.

To enter and fly in a TRSA, under VFR conditions, a pilot must have a valid pilot's license (at least a private), a functioning 2-way radio, a serviceable sensitive pressure altimeter and a gyro-stabilized compass or directional gyro. At all times while flying in the TRSA, a listening watch on the frequency assigned to the TRSA must be maintained.

Before entering the TRSA, a pilot must have authorization from the appropriate Air Traffic Control unit and relay the following information: type and registration (in phonetic letters) of his aircraft; position (either by an accurate fix using a map or by a VOR radial and distance) to enable the controller to make an identification on his radar screen; altitude and if climbing or descending; destination; and transponder status. If the airplane is transponder equipped, the code 1200 should be selected. If ATIS is available, the pilot should obtain this information prior to contacting the TRSA controller and so inform him on the initial contact.

The controller will then vector the aircraft to its destination, maintaining separation from IFR and other VFR traffic.

ATC authorization for flight in a TRSA does not relieve the pilot of the responsibility of avoiding other aircraft, of maintaining terrain and obstruction clearance and of remaining in VFR weather conditions.

RESTRICTED AIRSPACE

There are blocks of airspace throughout the country through which flight is either prohibited or restricted. These areas are indicated on aeronautical charts by hatched lines. They are identified by the letters "CY" to denote Canada, followed by an "A" for Alert, "D" for Danger or an "R" for Restricted or Prohibited. Each area also has an identifying three digit number. The first digit of the number identifies the geographic area of Canada in which the Restricted Area is situated (e.g. "1" for B.C., "2" for Alta., "3" for Sask., etc.). In the case of Alert Areas, a letter in brackets follows the number to indicate the type of activity within the Area. (A) indicates aerobatics, (P) parachute dropping, (T) training and (S) soaring. Thus, an area coded CYA 511(T) denotes training activity in Alert Area 511 in Ontario, Canada.

Information about the altitudes and times of use are also given on the aeronautical charts.

A series of red and green pyrotechnical lights fired at regular intervals may be used to warn a pilot to stay away from a Restricted, Prohibited or Danger Area.

RESTRICTED AREA

Restricted Areas are areas through which flight is either completely prohibited or restricted to certain specified conditions. They are usually centred on areas where activity hazardous to aircraft may occur, such as military bases, nuclear research establishments, missile testing ranges and aerial gunnery ranges.

DANGER AREAS

A Danger Area is an airspace of defined dimensions within which activities constituting a potential hazard to aircraft may exist. Flight through such areas is not prohibited although it may be just as hazardous as in Restricted Areas.

ALERT AREAS

An Alert Area is an area in which a high volume of pilot training or unusual type of aerial activity is carried out. Flight within an Alert Area is not restricted but pilots should exercise caution within this airspace.

AIR TRAFFIC RULES AND PROCEDURES

For flight within Canadian airspace, there are many procedures and regulations which a pilot must know and which he must follow to ensure separation from other traffic and the safe and efficient operation of his own flight. Procedures and regulations are constantly undergoing change and it is a pilot's responsbility to keep himself informed of such changes by consulting the Air Navigation Orders and the most recent issue of the **Flight Information Manual**.

DEFINITIONS

AIR TRAFFIC means all aircraft in flight and those maneuvering on the ground in the area of an airport.

AIR TRAFFIC CONTROL (ATC). A service operated to promote the safe, orderly and expeditious flow of air traffic. It includes Area (Can) ARTC (US) Control Centres, Airport Control Towers, Terminal (Can) Approach (US) and Ground Control facilities.

AIR TRAFFIC CONTROL UNIT. An area control centre established to provide air traffic control service to IFR flights; a terminal control unit established to provide air traffic control service to IFR flights operating within a terminal control area; or an airport control tower unit established to provide air traffic control service to airport traffic.

AIR TRAFFIC CONTROL CLEARANCE. An authorization from an ATC unit for an aircraft to proceed within controlled airspace under specified conditions. Acceptance of an Air Traffic Control Clearance or Instruction (below) does **not** relieve the pilot of the responsibility of avoiding other traffic. If all or part of an Air Traffic Control Clearance is unacceptable to him, because, for example, of the operational capabilities of himself or his airplane, the pilot must so inform ATC and ask for other instructions. Even after accepting a Clearance, if the pilot subsequently finds that he cannot comply, he should so inform ATC and ask for new directions.

AIR TRAFFIC CONTROL INSTRUCTION. A directive issued by an ATC unit for air traffic control purposes.

AIR TRAFFIC CONTROL SERVICE. A service provided for the purpose of expediting and maintaining the flow of air traffic and for the purpose of preventing collisions both in the air and on the ground.

APPROACH (U.S.) ARRIVAL (Can.) and DEPARTURE CONTROL. An air traffic control service provided by a Terminal Control facility for arriving and/or departing IFR flights.

CENTRE (AREA CONTROL CENTRE). A unit located within a Control Area which provides supervision of IFR en route air traffic within the area. In the U.S., it is called an Air Route Traffic Control Centre (ARTC).

CONTROL TOWER. A unit which exercises control over traffic arriving at, departing from, or flying in the vicinity of an airport, and control over all ground traffic in the area.

CONTROLLED AIRPORT. An airport at which an air traffic control unit is provided.

CONTROLLED AIRSPACE. An airspace of defined dimensions within which air traffic control service is provided.

CUSTOMS NOTIFICATION SERVICE (ADCUS). A service provided, on request, by ATC units for advance notification to Customs officials for trans-border flights at specified Ports of Entry.

"ELSEWHERE" is any area outside the boundaries of a Control Zone, Control Area and is usually called a Flight Information Region.

FLIGHT INFORMATION AREA. An airspace of defined dimensions extending upwards from the surface of the earth in which an Area Control Centre will provide flight information service to aircraft and warn search and rescue organizations when aircraft become overdue. Flight Information Regions include the 700-foot space which lies below Control Areas. They may include Aerodrome Traffic Zones. (Can.).

FLIGHT SERVICE STATION (U.S.). An airway radio, teletype or other communication station operated by the F.A.A.

GROUND CONTROL. A tower facility which handles the movement of aircraft on the ground, prior to take-off and subsequent to landing.

MILITARY FLYING AREA. An airspace of defined dimensions within the High Level Airspace designated for military training and testing.

POSITION REPORT. A report from an airplane en route to ATC, made upon passing a Reporting Point. A Position Report must include identification of the aircraft, position, time of passing the Reporting Point, altitude, type of Flight Plan, estimated time of arrival at the next Reporting Point, and the name of that next Reporting Point (to identify the route).

PRIVATE AIRPORT. An airport in respect of which a private airport license has been issued.

REPORTING POINT. A geographical location in relation to which the position of an airplane is reported. Compulsory Reporting Points are shown on Radio Facility Charts as solid triangles ▲ , non compulsory Reporting Points as outline triangles △ . Reporting Points are usually aeradio stations (VOR). However, they may be non-directional radio beacons, or the intersection of an omni radial with the radial which lies along the airway being flown. (In the latter case, an arrow indicates the direction of the intersecting position line.)

FLIGHT RULES

VISUAL FLIGHT RULES (VFR)). The rules which apply when flying by means of visual reference to the ground.

INSTRUMENT FLIGHT RULES (IFR). The rules which apply when flying by means of reference to the instruments in the cockpit.

It is the responsibility of the pilot in command to determine whether a flight will be conducted in accordance with Visual or Instrument Flight Rules.

IFR Flight is only permissible when the pilot has a valid instrument rating and the airplane is suitably instrument and radio equipped for IFR flight.

Visual Flight Rules only are dealt with in this manual.

FLIGHT PLANS

For any VFR flight that will be conducted beyond a radius of 25 miles from the airport of departure, the pilot in command is required to file a VFR Flight Plan or a VFR Flight Notification with ATC or to leave with a responsible person a Flight Itinerary.

Notwithstanding the above, a VFR Flight Plan must be filed for any flight to or from a military aerodrome. (Prior permission from the military authorities is also required before landing at a military field.)

A VFR Flight Plan must also be filed for any transborder flight between Canada and the United States, and for any flight that will penetrate a Canadian Air Defence Identification Zone (applicable only to airplanes with a cruising speed of 180 knots or more).

In the sparsely settled areas of Canada where communication facilities are inadequate to permit either submitting a Flight Plan to ATC or closing it after arrival, the pilot has the choice of filing a VFR Flight Notification with whatever ATC unit is available to him or of notifying a responsible person of his Flight Itinerary.

VFR FLIGHT PLAN

A VFR Flight Plan should contain the following information:

a) the aircraft registration and type
b) the type of transponder equipment installed in the aircraft
c) the proposed true airspeed in knots at cruising altitude
d) the point of departure or the position of the aircraft if the information is filed while the aircraft is in flight
e) the route to be followed, including landings at intermediate airports
f) the destination airport
g) the proposed time of departure
h) the estimated time enroute to or estimated arrival time at destination
i) the amount of fuel on board expressed in hours and minutes
j) the type of emergency locator transmitter
k) the type of communication equipment to be used enroute or the word RONLY meaning receiver only or the word NORDO meaning no radio
l) the type of navigation equipment installed in the aircraft
m) the total number of persons on board at the point of first departure
n) the licence number and name of the pilot in command
o) the colours of the aircraft
p) the nature of any hazardous or dangerous cargo on board
q) such additional information as considered relevant by the pilot or requested by ATC
r) cruising altitudes or the abbreviation VFR where no specific altitude is to be maintained.

A U.S. VFR Flight Plan requests basically the same information in a somewhat different order.

Flight Plans may be filed at an Air Traffic Control unit either directly or through a communication base such as an aeradio station, an airport office, an operations office such as a flying club or a fixed base operator or they may be telephoned to ATC. It is not advisable, because of possible overloading, to use the air-ground communication frequencies for filing Flight Plans when any alternate method is available. A single Flight Plan may be filed for a flight that will include one or more stopovers as long as the stopovers are of short duration (e.g. boarding passengers, refuelling, etc.). The stops must be indicated on the Flight Plan.

Closing of a Flight Plan, i.e. reporting your arrival, must be submitted to an ATC unit or an appropriate communications base such as an aeradio station within one hour after landing. If this is not done, Air Traffic Control will contact stations along your intended route and if they are unable to obtain information as to your whereabouts, they will contact the Search and Rescue Service. In the event that you have had to terminate your VFR flight at an aerodrome other than the one to which the flight was planned or if you have had to make any changes in the flight route, ETA, etc., you must notify ATC as soon as possible of the change in the Flight Plan.

The pilot is at all times responsible for the closing of his Flight Plan and should never assume that the tower personnel will automatically file an arrival report. An arrival report should include the aircraft registration, the aerodrome of departure, the time and aerodrome of arrival.

Once you have filed a Flight Plan or Flight Notification or a Flight Itinerary, **follow it.** If a deviation from your intended route or altitude becomes necessary, advise an Aeradio or Flight Service Station (US). Otherwise, in the event of a crash or forced landing, rescue planes may lose valuable time searching for you in the wrong place.

FLIGHT NOTIFICATION

A Flight Notification is used whenever a VFR flight is made wholly or partially within the sparsely settled areas where the pilot cannot meet the arrival report requirements of a Flight Plan.

A Flight Notification should contain the same information that is required on a Flight Plan (a to q above) with the exception of (r). In addition, the pilot must advise what overnight stops he intends to make, if any, and whether his aircraft is equipped with wheels, skis, floats or a combination of these.

Arrival reports must also be submitted for Flight Notifications but more time is allowed to do this than is the case with a Flight Plan. The pilot has 24 hours from the time he indicated on his Flight Notification that he expected to arrive at his destination to file his arrival report with an ATC unit.

FLIGHT ITINERARY

With the exception of VFR flight to and from a military aerodrome or flight within an Identification Zone, pilots are now permitted to file a Flight Itinerary in lieu of a VFR Flight Plan or Flight Notification provided the Itinerary is filed with a responsible person.

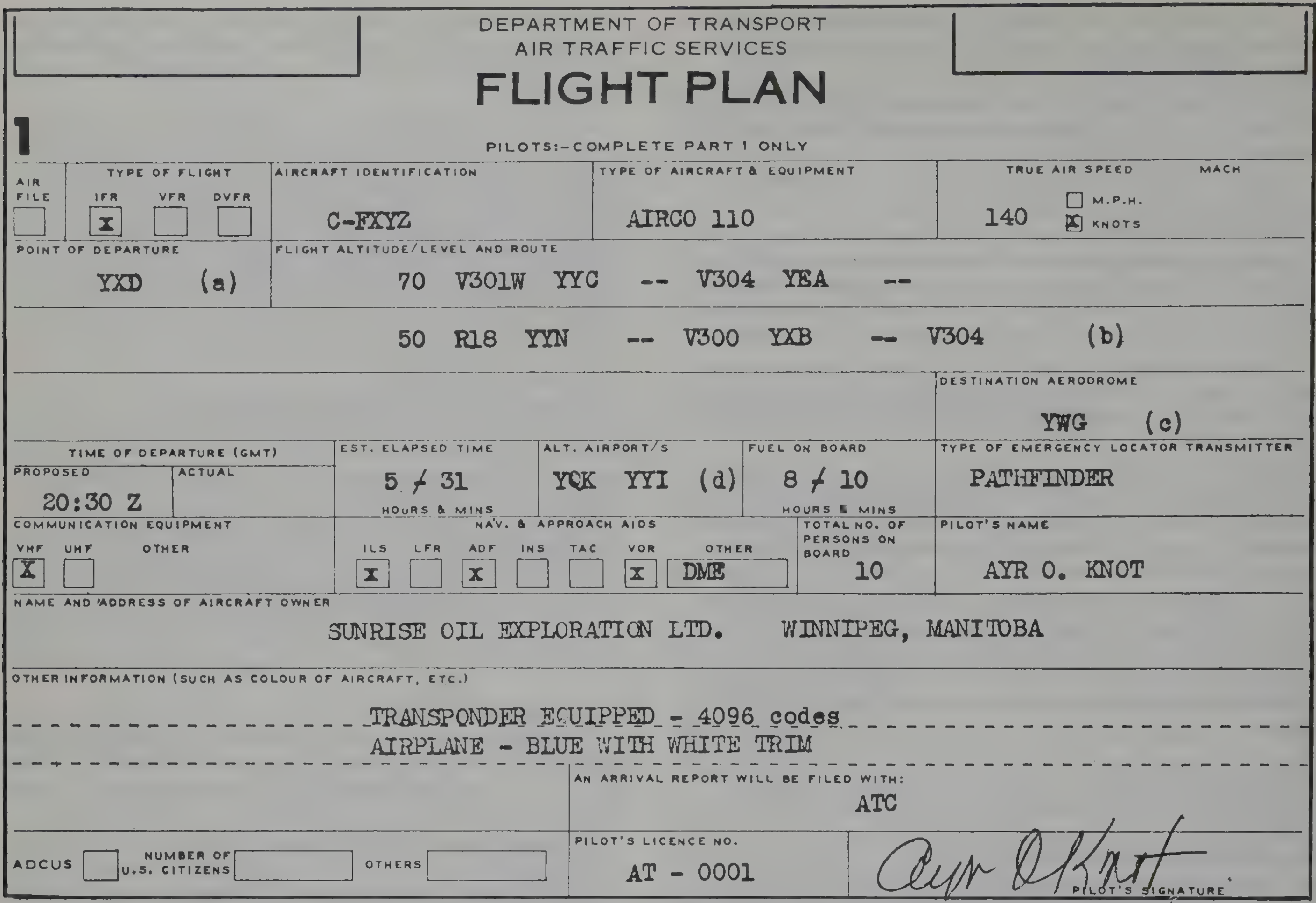
A Flight Itinerary should contain the following information:

a) Aircraft registration and type
b) Estimated duration of flight and ETA at destination
c) Route of flight
d) Location of overnight stops, if applicable.

Upon the termination of a flight for which a Flight Itinerary was left with a responsible person, the pilot must inform this person of his arrival within 24 hours. It is the responsibility of that person to notify ATC, an aeradio station or a peace officer should the pilot fail to arrive at the ETA specified in his Flight Itinerary.

TRANS BORDER FLIGHTS

First of all, a Flight Plan must be filed for any flight that crosses the border into the United States. Strictly speaking, the Canadian Customs regulations are such that all flights, both of a commercial and private nature, can be required to clear outward from Canada when proceeding to points in the U.S.A. or beyond. However, in actual practice, private flights (but not



DEPARTMENT OF TRANSPORT
AIR TRAFFIC SERVICES
FLIGHT PLAN

1

PILOTS:-COMPLETE PART 1 ONLY

AIR FILE ☐
TYPE OF FLIGHT: IFR ☒ VFR ☐ DVFR ☐
AIRCRAFT IDENTIFICATION: C-FXYZ
TYPE OF AIRCRAFT & EQUIPMENT: AIRCO 110
TRUE AIR SPEED: 140 ☐ M.P.H. ☒ KNOTS
MACH:
POINT OF DEPARTURE: YXD (a)
FLIGHT ALTITUDE/LEVEL AND ROUTE: 70 V301W YYC -- V304 YEA --
50 R18 YYN -- V300 YXB -- V304 (b)
DESTINATION AERODROME: YWG (c)
TIME OF DEPARTURE (GMT): PROPOSED 20:30 Z ACTUAL
EST. ELAPSED TIME: 5 / 31 HOURS & MINS
ALT. AIRPORT/S: YQK YYI (d)
FUEL ON BOARD: 8 / 10 HOURS & MINS
TYPE OF EMERGENCY LOCATOR TRANSMITTER: PATHFINDER
COMMUNICATION EQUIPMENT: VHF ☒ UHF ☐ OTHER
NAV. & APPROACH AIDS: ILS ☒ LFR ☐ ADF ☒ INS ☐ TAC ☐ VOR ☒ OTHER DME
TOTAL NO. OF PERSONS ON BOARD: 10
PILOT'S NAME: AYR O. KNOT
NAME AND ADDRESS OF AIRCRAFT OWNER: SUNRISE OIL EXPLORATION LTD. WINNIPEG, MANITOBA
OTHER INFORMATION (SUCH AS COLOUR OF AIRCRAFT, ETC.): TRANSPONDER EQUIPPED - 4096 codes
AIRPLANE - BLUE WITH WHITE TRIM
AN ARRIVAL REPORT WILL BE FILED WITH: ATC
ADCUS ☐ NUMBER OF U.S. CITIZENS ☐ OTHERS ☐
PILOT'S LICENCE NO.: AT - 0001
Ayr O Knot
PILOT'S SIGNATURE

Fig. 9. Canadian Flight Plan.

An IFR Flight Plan has been chosen as an example because it meets all the complete requirements for flight planning. VFR Flight Plans are somewhat less detailed. In the example above: (a) indicates that the point of departure is YXD (Edmonton). (b) states the initial cruising altitude will be 70 (7000 ft.) via V301W (Victor Airway 301W) to YYC (Calgary) — thence via V304 (Victor Airway 304) to YEA (Empress, Alta.) From this point, the cruising altitude will be 50 (5000 ft.) via R18 (Red Airway 18) to YYN (Swift Current) — thence via V300 (Victor Airway 300) to YXB (Broadview, Sask.) and via V304 (Victor Airway 304) to (c) the point of first intended landing, YWG (Winnipeg). (d) names the alternate airports YQK (Kenora) and YYI (Rivers). This latter information is not required in a VFR Flight Plan. Other portions of the sample Flight Plan should be completely self-explanatory.

commercial flights) are permitted to depart for points in the U.S.A. without first obtaining an outward clearance from Canadian Customs authorities. Having crossed the border, the first landing must be made at a U.S. Customs Port of Entry to clear customs inward. Upon returning to Canada, private flights are not required to clear outwards from the U.S.A. (Commercial flights of any kind, i.e. charter, air taxi, cargo, etc., must often meet special requirements to comply with the laws of the United States.) The first landing in Canada after taking-off from a point in the U.S.A. must be made at a Canadian Customs Port of Entry. Regulations require that you notify the Customs authorities of your expected time of arrival in advance. Upon landing, you **must not leave your airplane** until Customs and Immigration officers arrive at the airport to clear you. On trans-border flights you must have your pilot's licence in your possession and the airplane registration and airworthiness certificates must be on board.

If you add "ADCUS" (Advise Customs) to your Flight Plan, ATC will automatically notify the Customs authorities of your estimated time of arrival. This saves you the inconvenience of sending a wire or making a long distance phone call. (Flight planning from U.S. points to Mexico, add "ADMISA", which is the Spanish language abbreviation for "Advise Customs and Public Health Service"). On flights from Canada to the United States, the number of U.S. and non-U.S. citizens on board must be included in the Flight Plan — e.g.: "ADCUS — 2 US — 2 Non". On flights from the United States to Canada this information is not required.

Customs and Immigration information, including listings of Customs Ports of Entry, will be found in both the Canadian and U.S. **Flight Information Manuals.**

CRUISING ALTITUDES

Cruising altitudes appropriate to the direction of flight must be maintained at all times regardless of whether a Flight Plan has, or has not, been filed.

In the Southern Domestic Airspace, cruising altitudes are based on magnetic headings. In the Northern Domestic Airspace, cruising altitudes are based on true headings.

Altitudes below 18,000 feet are stated in thousands of feet. Altitudes at or above this height are referred to as Flight Levels (i.e. FL 180).

On airways, IFR cruising altitudes are assigned by ATC. In uncontrolled airspace, a cruising altitude appropriate to the direction of flight should be chosen by a pilot and maintained.

In Fig. 10, the shaded hemispheres refer to tracks flown from 000° to 179°; the white hemispheres are for tracks from 180° to 359°.

CRUISING ALTITUDES — CANADA

VFR, Controlled VFR and IFR — On or Off Airways

At altitudes below FL 230

000°-179° — Fly ODD thousands (1000'-3000' MSL etc. FL's 190-210 etc.)

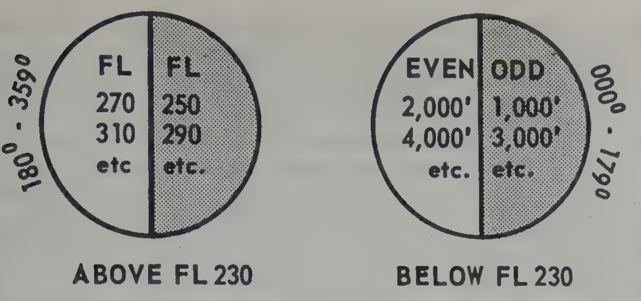


Fig. 10. Cruising altitudes — Canada.

180°-359° — Fly EVEN thousands (2000’-4000’ MSL etc. FL’s 200-220 etc.)

At altitudes above FL 230

000°-179° — Fly at 4000’ intervals beginning at FL 250 (FL’s 250 - 290 - 330 - 370 - 410 - 450)

180°-359° — Fly at 4000’ intervals beginning at FL 270 (FL’s 270 - 310 - 350 - 390 - 430 - 470)

In level cruising flight, at or below 3500 feet AGL, the specified cruising altitudes are not compulsory but should be flown if practicable.

CRUISING ALTITUDES — U.S.

Because most Canadian pilots sooner or later will embark on a cross country flight that will take them into the United States, the U.S. cruising altitudes, which are slightly different than the Canadian ones, are explained here.

VFR — On or Off Airways

At altitudes below FL 290 (But above 3000’)

000°-179° — Fly ODD thousands plus 500 ft. (3500’-5500’, etc. MSL)

180°-359° — Fly EVEN thousands plus 500 ft. (4500’-6500’, etc. MSL)

At altitudes above FL 290

000°-179° — Fly at 4000’ intervals beginning at 30,000’ Pressure Altitude. (Flight Level 300-340, etc.)

180°-359° — Fly at 4000’ intervals beginning at 32,000’ Pressure Altitude. (Flight Level 320-360, etc.)

Note: Altitudes for VFR apply to “VFR on top”

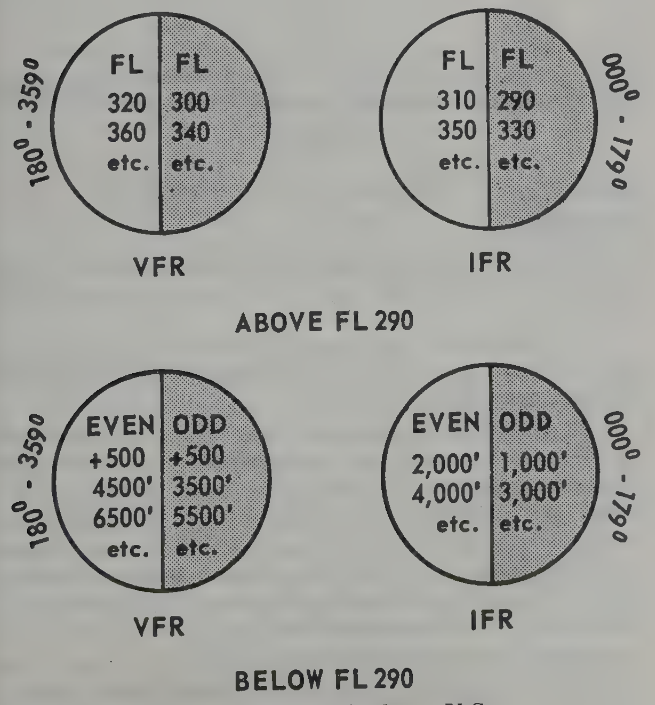


Fig. 11. Cruising altitudes — U.S.

IFR — On or Off Airways

At altitudes below FL 290

000°-179° — Fly at ODD thousands (1000’-3000’, etc. MSL or Flight Level 190-210 etc.)

180°-359° — Fly at EVEN thousands (2000’-4000’, etc. MSL or Flight Level 180-200 etc.)

At altitudes above FL 290

000°-179° — Fly at 4000’ intervals beginning at 29,000’ Pressure Altitude. (Flight Level 290-330, etc.)

180°-359° — Fly at 4000’ intervals beginning at 31,000’ Pressure Altitude. (Flight Level 310-350, etc.)

MINIMUM CRUISING ALTITUDES

MOCA—**Minimum Obstruction Clearance Altitude** is the minimum MSL altitude along an airway segment which will permit the airplane to clear obstructions by 1000 ft.

MEA—**Minimum En Route Altitude** is the minimum MSL altitude which will clear obstructions and also permit satisfactory radio reception and is the minimum altitude to be considered for IFR flight plans. (See **“Table of VHF Reception Distance”**)

Both MOCA and MEA are indicated on Enroute Radio Facility Charts.

CRUISING SPEEDS

All Canadian **controlled** airspace below 10,000 feet ASL is considered as a “speed limit area”, and all aircraft must conform to the regulations pertaining to operation within this area. Within 10 nautical miles of a controlled airport, and at an altitude less than 3000 feet AGL, airplanes with reciprocating engines must reduce their speed to less than 156 knots (180 mph). Turbine powered airplanes must maintain an airspeed of less than 200 knots (230 mph).

In controlled airspace but beyond the 10 nautical mile limit around controlled airports, the airspeed limit is 250 knots (288 mph).

Only if the minimum safe speed for a particular aircraft is greater than the above mentioned speeds, may the aircraft be operated at a higher speed.

WEATHER MINIMA FOR VFR FLIGHT

Within Control Zones

Ground Visibility	3 miles
Distance from Cloud	500’ vertically 1 mile horizontally
Height above surface	500’

In addition to the above, to operate VFR in a Control Zone, the ceiling must be not less than 1000 feet.

Within Control Areas

Flight Visibility	3 miles
Distance from Cloud	500’ vertically 1 mile horizontally

Aerodrome Traffic Zones

Ground Visibility	3 miles
Distance from cloud	500’ vertically 1 mile horizontally
Height above surface	500’

Elsewhere (other than Controlled Airspace and Aerodrome Traffic Zones)

At or above 700’ above surface

Flight Visibility	1 mile
Distance from clouds	500’ vertically 2000’ horizontally

Below 700’ above surface

Flight Visibility	1 mile
Distance from clouds	Clear of cloud

Within Controlled Airspace (U.S.)

In the U.S., weather minima for VFR are slightly different. VFR on top is permitted. It is not legal in Canada.

1200 feet or less above the surface

Visibility	3 miles
Distance from clouds	500' below 1000' above 2000' horizontally

More than 1200 feet above the surface

Visibility	3 miles
Distance from clouds	500' below 1000' above 2000' horizontally

More than 10,000 feet above the surface

Visibility	5 miles
Distance from clouds	1000 feet above 1000 feet below 1 mile horizontally

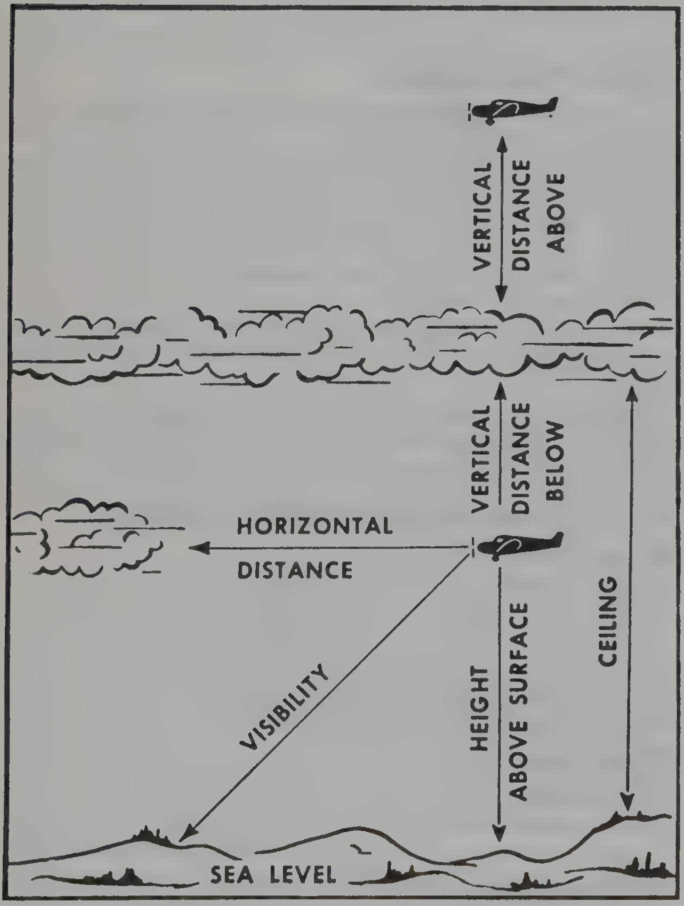


Fig. 12. Weather minima references.

SPECIAL VFR

Within Control Zones, Air Traffic Control may authorize a pilot to fly **Special VFR** under weather conditions that are below VFR minima. **Special VFR** requires the airplane to be clear of cloud and within sight of the ground at all times. The following minimum ceilings and visibilities apply:

Airplanes without radio: Ceiling of 800 feet and ground visibility of 1 mile or 1600 meters. The airplane must be within sight of the Control Tower at all times.

Airplanes with receiver only: Ceilings of 800 feet and ground visibility of 1 mile or 1600 meters.

Airplanes with functioning two way radio: Ceiling of 500 feet and ground visibility of 3 miles or 5 kilometers; or, ceiling of 600 feet and ground visibility of 2 miles or 3200 meters; or, ceiling of 700 feet and ground visibility of 1 mile or 1600 meters.

Helicopters with functioning two way radio: Ceiling of 300 feet and ground visibility of 1 mile or 1600 meters. The helicopter must be operated at reduced airspeed to avoid collision hazard.

In addition, it remains the responsibility of the pilot to avoid weather conditions that are beyond his own flying capabilities or the capabilities of his airplane. It is also his responsibility to maintain adequate clearance from any obstructions in his flight path.

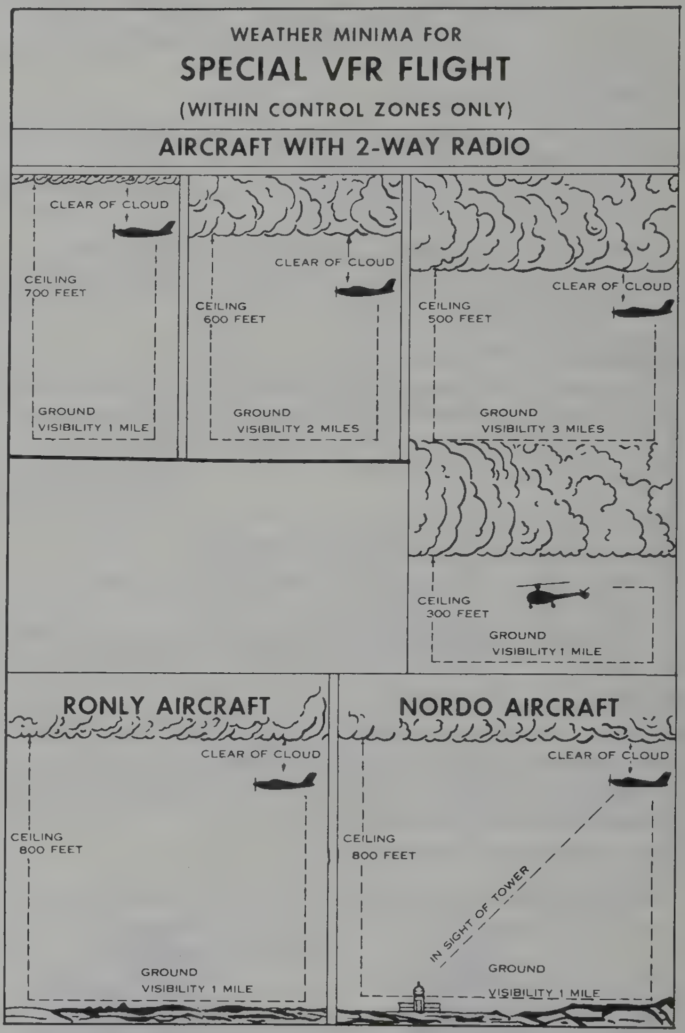


Fig. 13. Special VFR.

CONTROLLED VFR (CVFR) - BLOCK AIRSPACE

The Block Airspace is part of the controlled airspace system. VFR flight is permitted, but only under Controlled VFR (CVFR).

To be qualified to fly Controlled VFR, a pilot must have either an instrument rating or an endorsement to his license "Valid for Block Airspace".

Controlled VFR flights must be conducted in accordance with procedures designed for use by IFR flights. However, the flight must be conducted in VFR weather conditions (i.e. weather minima for Control Areas) with visual reference to the ground.

Before entering the Block Airspace, the pilot in command of the airplane must file a VFR Flight Plan stating the altitude at which the flight is to be conducted and the route that is to be followed. (e.g. Flight Altitude 12,000/VFR, Route V71).

Clearance for VFR flight within the Block Airspace is given only if the altitude requested is available and if traffic conditions are such that the flight can be accommodated. Clearance is not usually given prior to take off but rather upon receipt of a position report that the flight has reached the last 1000 foot altitude below the base of the Block Airspace.

A functioning two way radio is, of course, essential and throughout the flight, the pilot must maintain a listening watch on the appropriate radio frequency and must make position reports as required by the ATC unit.

The pilot is responsible at all times for maintaining VFR flight. If the weather observed ahead falls below VFR minima, he must leave the designated airway without climbing or descending and when clear of the airway take whatever action is necessary to continue the flight under VFR conditions. As soon as possible, ATC must be informed of the action taken.

It is essential that the assigned altitude be maintained with precision and that no deviation be made from the clearance without advising ATC.

It may seem that the Block Airspace is just another unnecessary complication for the average pilot. However, it is common practice for airlines to fly Instrument Flight Rules most of the time regardless of the weather, and they probably are not looking out of the window watching for unexpected traffic. With modern high speed airplanes, the rate of closing between two approaching airplanes can be in excess of 500 miles an hour — or 8 miles a minute. This means that with 3 miles visibility, a 200 mile-an-hour airplane approaching a 300 mile-an-hour airplane would have 22 seconds to alter course. In practise, the time is not so long. There is a lag between the time the pilot sights another airplane and the time that he takes corrective action. There is a further lag in the response of the airplane. These "lags" take up an average of 15 seconds, leaving 7 seconds to avoid a collision. The object of Controlled VFR, like IFR, is to prevent collision by controlled separation of the movement of all aircraft within control areas by an Air Traffic Control Centre.

To prepare for a CVFR flight, check the appropriate En Route Radio Navigation Charts for distances between reporting points along the route. Take along a computer.

You are required to make position reports en route when passing all compulsory reporting points or when requested by ATC. On filing a position report, it is necessary to state your estimated time of arrival at the next reporting point. This means that you have to compute groundspeeds and ETA's as you go.

ATC will clear you to a specific point. This may be your destination airport, an omni or other radio station, or a reporting point en route. The location to which you are cleared is known as the **Clearance Limit.**

Should you arrive at the Clearance Limit without clearance beyond, or holding instructions, you must immediately request further clearance and meanwhile **hold** at the assigned altitude. The reason for this is that another airplane may be flying at your altitude beyond this point. (If you do not wish to hold, however, you may request a clearance to descend below Block Airspace.)

A Flight Plan may not be changed en route without authority from an ATC Centre. If you should desire to make a change in altitude, route or destination, obtain an amended clearance from ATC.

EMERGENCY WHILE CVFR

If instrument weather conditions are encountered, leave the airway immediately without climbing or descending. Advise ATC as soon as possible of your action.

In the event of radio failure, leave the airway immediately maintaining your last assigned altitude. When clear of the airway, proceed, remaining well clear of the airway, or descend below the Block Airspace and return to the airway. In either case, the weather conditions you are flying in must be VFR. Report your action as soon as possible after landing.

In the event of engine failure or any other cause necessitating an immediate descent, advise ATC immediately (using the emergency frequency 121.5 MHz if necessary).

HOLDING PATTERN

There are several situations in flying in which a pilot may be asked to **hold** over a particular fix. This can happen in CVFR flight if clearance to proceed past a Clearance Limit cannot be given. Sometimes on arrival at an airport, a pilot is asked to hold over a beacon until landing clearance can be given (IFR flights).

For the pilot on a CVFR flight, since he is maintaining visual reference to the ground, a precise Holding Pattern is not absolutely necessary. It is, however, good practice to learn to fly a Holding Pattern precisely.

The standard form of Holding Pattern is the elliptical, or "race track" pattern. It is illustrated and explained in Fig. 14. The holding fix may be a marker beacon, VOR, non-directional radio beacon or any facility which can be definitely identified by a radio signal when you are directly overhead.

Do not leave the Holding Pattern until cleared by ATC to do so.

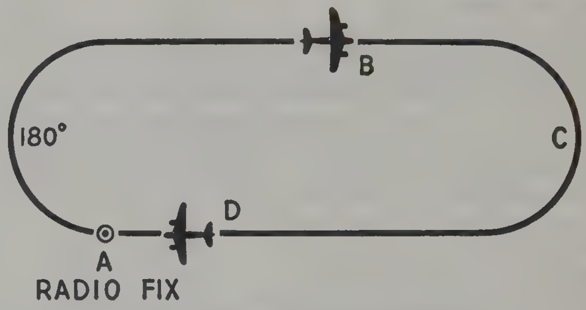


Fig. 14. Standard holding pattern.

Over Radio Fix at A, start Rate One Turn to right (180°—1 minute.) Fly 1 minute outbound, B. Execute Rate One Turn to right at C. Fly inbound course to Radio Fix, D—parallel to B. (Note: The wind should be compensated for.) The Holding Pattern is flown in a specified direction in relation to the Holding Fix. Assuming the top of the page to be North, the holding pattern illustrated would be East and the Aircraft would be said to be "Holding East of (name of Radio Fix)". The Track outbound (B) would be 90° and the Track inbound (D) 270°. Note: The outbound time should be increased or decreased, according to the wind conditions, to effect 1 minute inbound to the fix.

POSITIVE CONTROLLED AIRSPACE

Within Positive Controlled Airspace, IFR traffic **only** is permitted to operate, at altitudes assigned by ATC. In Canada, the airspace in which positive control is mandatory includes the Arctic Control Area, the Northern Control Area and the Southern Control Area. In the U.S., the Positive Control Area commences at 18,000 feet ASL and extends up to FL 600.

IDENTIFICATION ZONES

Special procedures are in effect for airplanes operating in the Defence Identification Zones. These rules are applicable, however, only to airplanes with a cruising speed of 180 knots or more.

To enter or fly within a CADIZ, it is necessary to file an IFR Flight Plan (if on instruments), or a DVFR Flight Plan or Defence Flight Notification (if VFR). No deviation from the Flight Plan is permitted without prior notification to an Air Traffic Control unit. When prior notification is impossible, ATC must be advised of the deviation as soon as possible.

A functioning two way radio is required equipment and the pilot must maintain a listening watch on the appropriate frequency throughout the time that he is within the boundaries of the Identification Zone.

Before entering an Identification Zone, a pilot on either an IFR or DVFR Flight Plan must report the time, altitude and position at which his airplane passed over the last reporting point and the estimated time, altitude and position over the point of penetration of the Zone or the next reporting point.

Revised estimates must be reported if the airplane will not be within 5 minutes of its forecast time of arrival at a reporting point, penetration point or destination. Deviations of more than 10 miles from course must also be reported.

An Arrival Report must be filed when closing a DVFR or Defence IFR Flight Plan.

In the event of an emergency, the SCATANA Rules are put into effect. For this reason, pilots should maintain a listening watch on an Air Traffic Control frequency at all times. When notified that SCATANA rules are in effect, pilots must comply with all instructions from ATC. VFR and IFR flights may be ordered to change course, or altitude or even to land at the nearest facility. On such occasions, a pilot planning a flight within the DEWIZ or CADIZ must obtain approval for the flight prior to take-off and must provide position reports at least every 30 minutes during the flight.

There are a few variations to these rules which apply to flight within a Coastal CADIZ or the DEWIZ. They are explained below.

COASTAL CADIZ

The pilot of an airplane that will operate within a Coastal CADIZ approaching the Canadian Land Mass must file an IFR Flight Plan, a DVFR Flight Plan or a Defence Flight Notification before taking off from his last location and must make position reports and estimates as required in Instrument Flight Rules. If the airplane will not be within 5 minutes or 20 nautical miles of its estimated time or position, the pilot must advise the appropriate Air Traffic Control unit.

DEWIZ

The regulations regarding the filing of Flight Plans, penetration, position reports and revised position reports are similar to those which apply to CADIZ. The DVFR Flight Plan or Flight Notification, however, **must contain an estimate of the time and point of penetration**. Deviation from the estimated time or position must be reported to an Air Traffic Control unit or DEWIZ beacon.

ATC facilities are less numerous in the remote DEWIZ areas, but non-directional beacons have been established within these zones. Pilots must establish communication with these beacons **as soon as possible**. Airplanes which have not been able to file a Flight Plan may be required to fly at reduced airspeed, to land, or to proceed to a specified area for positive identification.

SPARSELY SETTLED AREAS

To fly in the Sparsely Settled Areas of Canada, an airplane must be capable of two way radio communication with a ground station in the area. An Emergency Locator Transmitter of an approved type that transmits on the distress frequency is mandatory. A portable manually activated ELT is a recommended extra.

Certain survival equipment is also mandatory. It is defined in ANO V. No. 2 and includes:

Food having a calorific value of at least 10,000 calories per person stored in sealed waterproof containers.

Cooking utensils (tea pail, frying pan, plates, utensils). Primus or similar self contained stove. Matches in four separate waterproof containers. (One should be carried on the person of the pilot.)

An axe of 2½ lbs with a 28" handle. A spare axe handle and a honing stone or file. A sharp jackknife or hunting knife. A flexible saw blade. Fish net. 4 trawls, 2 hooks, lines and sinkers. 30 ft. snare wire (4 oz.). Pocket compass.

Mosquito nets and a sufficient supply of insect repellent for all persons.

Tents or engine covers of high intensity colour. One sleeping bag for each person.

Two pairs of snowshoes (in winter).

A signalling mirror. At least 3 pyrotechnical distress signals. A conspicuity panel.

In addition to the required equipment, experienced bush pilots carry candles to assist in lighting a fire, a small sewing kit to mend tears in clothing to prevent frostbite, a flashlight with spare bulb and batteries.

UNCONTROLLED AIRSPACE

Within the uncontrolled airspace in Canada, aircraft may operate free of the control of an ATC unit. However, all aircraft are required at all times to conduct their activities with regard to the Air Regulations and Air Navigation Orders.

When cruising in uncontrolled airspace or when maneuvring in the vicinity of uncontrolled airports, the lack of information of other aircraft in close proximity may constitute a potential hazard. Pilots, therefore, are advised to monitor continuously the frequency 122.2 MHz whenever practicable and to broadcast their own intentions on 122.2 MHz before initiating a change in flight attitude. Such a broadcast should include the last known position, the estimated next position, the present altitude and intention (climb/descent) and the planned altitude.

When approaching an airport that has an Aeradio Station but no Control Tower, all pilots should establish contact with the Aeradio Station on 122.2 MHz and provide details of their landing or enroute intentions. If the airport has a UNICOM facility, contact should be made on the UNICOM frequency 122.8 MHz.

Radio . . .

Radio is the modern magic genie that creates invisible traffic arteries in the skies, whose voice reaches out to the airman in the overcast from the unseen world below—his guide to the weather that lies along his route, to the traffic pattern plan he must observe, to the vast amount of timely information he must receive to make flying as it is practised today a safe and practical undertaking.

Radio has been perfected to the point where it has come to be regarded in the present-day world of aviation as **indispensable.** While the vast airway radio networks of Canada and the United States offer rapid and reliable means of communication and air navigation, it should **never** be taken for granted that radio equipment is **infallible.** It can, and does, on occasion **fail.** Complete dependence on radio has provided the prelude to all too many an airplane disaster. A pilot should by all means make full use of his radio equipment. He should never, however, forget the simple traffic rules and signals that apply when his radio fails to function, nor cease to practise elementary navigation as a precaution against the time when he may be caught with his radio dead.

WAVE LENGTH AND FREQUENCY

When a stone is dropped in water (Fig. 1) waves are set up. While the height, or strength, of the waves grows weaker as they travel away from the point where the stone hit the water, the **length** of the waves (W.L.) never varies.

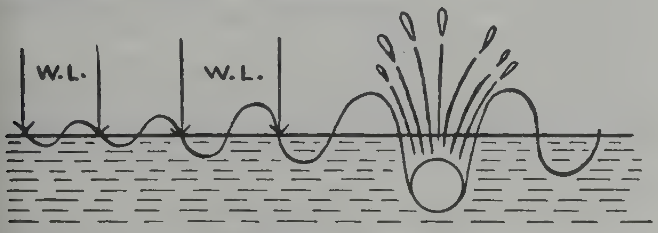


Fig. 1. Wave Length.

A radio transmitter sets up waves in the air in the same way that the stone does in water. The length of these waves remains constant, but the strength, or **Amplitude,** decreases with distance from the transmitting station.

The actual linear measurement of the wave is known as the **Wave Length** and is referred to in *meters.* The period in which the wave "vibrates", or rises and falls between its crest and trough, is called a **Cycle.** The number of cycles per second of time is called **Frequency.**

Very Low to High Frequencies are expressed in **Kilohertz (KHz),** that is, "thousands of cycles". For example, 3023.5 KHz stands for 3,023,500 hertz.

Very High Frequencies (VHF) are expressed in **Megahertz (MHz),** that is, "millions of cycles". For example 100 MHz stands for 100,000,000 hertz.

The relationship between *Wave Length* and *Frequency* is as follows: The Wave Length in meters is equal to 300,000 divided by the Frequency in Kilohertz.

Conversely, the Frequency in Kilohertz is equal to 300,000 divided by the Wave Length in meters.

NOTE: The speed of radio energy or light is 300,000,000 meters a second. This figure is divided by 1000 to equal 300,000, the figure used in the formulae above.

RADIO BANDS

The airway radio communication facilities and radio navigation aids operate in the L/F (Low Frequency), M/F (Medium Frequency), H/F (High Frequency), VHF (Very High Frequency) and UHF (Ultra High Frequency) bands.

Frequency Band Limits

Designation		Frequency		Wave Length Meters
VLF	Very Low	0 - 30	Kilohertz	300,000 - 10,000
LF	Low	30 - 300	"	10,000 - 1,000
MF	Medium	300 - 3,000	"	1,000 - 100
HF	High	3,000 - 30,000	"	100 - 10
VHF	Very High	30 - 300	Megahertz	10 - 1
UHF	Ultra High	300 - 3,000	"	100 - 10 cm
SHF	Super High	3,000 - 30,000	"	10 - 1 cm
EHF	Extremely High	30,000 - 300,000	"	1 - 1 mm

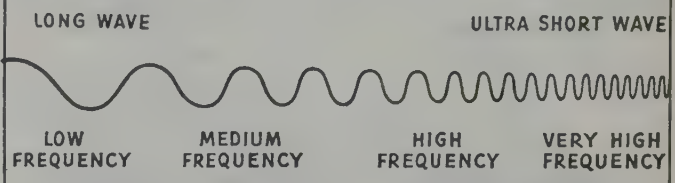


Fig. 2. Wave Length and Frequency.

LOW AND MEDIUM FREQUENCY

The L/MF Non-Directional Beacon Stations and Compass Locators transmit both voice and navigation signals on the Low Frequency band (200-415 KHz).

Commercial Broadcast Stations transmit in the medium wave band on frequencies between 550 KHz and 1500 KHz which is therefore known as the "Broadcast Band". Broadcast stations, as well as providing news and entertainment, can be used for directional bearings or "homing" with Automatic Direction Finding equipment.

HIGH FREQUENCY

Frequencies between 3,000 KHz and 30,000 KHz are known as High Frequencies.

Quite a number of frequencies in this range have been allocated to aviation. However, use of the High Frequencies has gradually decreased so that today only a few frequencies are still in use.

The frequency 5680 KHz is in constant use. This frequency was originally allocated to ground stations and aircraft operating in Northern Canada for use in emergency, when other normal frequencies are busy, have failed, or when an aircraft is not equipped with a ground station's normal frequency. It is now, however, also available to provide an air-ground communication channel to facilitate the reasonably long range communication requirements of non-scheduled air operations in the northern remote areas of Canada and on long overwater flights.

HF radio is especially valuable as a communications facility for long range use because of a special characteristic of HF radio waves. They are reflected back to Earth by the Ionosphere. (See below **Characteristics of Radio Signals.**) HF radio is therefore the only way to maintain constant contact at ranges of 2500 miles or more and therefore on transocean flights, pilots use it regularly to relay the position reports that they are required to give at every 5 degrees of longitude change.

Single Sideband HF

Because it permits communications to be established over considerable distance (several thousand miles in some cases), Single Sideband (S.S.B.) HF is becoming increasingly popular among airplane operators, particularly those who operate over wide areas where regular navigational aids and communication stations are non-existent. Relatively few pilots understand what S.S.B. is all about. The following short description will serve as a brief introduction.

S.S.B. is simply a method of compressing speech, or other intelligence, into a narrower band width. A fully amplitude modulated (A.M.) signal has two-thirds of its power in the carrier and only one-third in each of the sidebands. The sidebands carry the intelligence and the carrier serves only to denodulate the signal at the receiver. By eliminating the carrier and emitting only one sideband, available power is used to greater advantage. To recover the intelligence, the carrier must be re-inserted at the receiver. By this method, a gain of approximately 9 db over A.M. is obtained, equivalent to increasing the transmitter power 8 times.

In addition to the increase in power and range, S.S.B. communication conserves spectrum space. An S.S.B. voice signal requires less than 3 KHz of spectrum space, as opposed to the 7 or 8 KHz taken up by an A.M. signal.

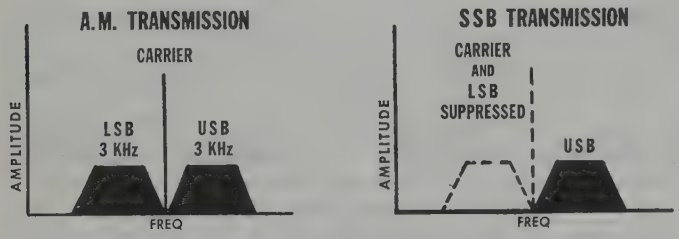


Fig. 3. Single Sideband.

Either the upper sideband (USB) or the lower sideband (LSB) may be employed. In more complex systems, both sidebands, with suppressed carrier, are used to convey two separate channels of intelligence.

The benefits of S.S.B. are greatest and most easily observed under poor propagating conditions. As a given transmission path deteriorates due to a combination of noise, severe selective fading and narrow band interference, the superiority of S.S.B. over A.M. is evident.

A pilot with an S.S.B. set installed in his airplane will be able to receive regular HF signals as well as the special S.S.B. signals. A regular HF receiver, however, is not receptive of S.S.B.

S.S.B. capability is being added to existing HF installations on 5680 KHz at northern stations.

VERY HIGH FREQUENCY

The VHF band lying between 30 MHz and 300 MHz is the most important from the pilot's point of view. Certain ranges of frequencies within this band have been allocated exclusively for aviation use for communications and for navigation aids.

The frequency range from 108.00 MHz through 117.95 MHz is used for navigation aids, such as the VHF Omninavigation Stations (VOR), and the Instrument Landing Systems (ILS). Voice reception is also provided on these frequencies.

The frequency range from 118.00 MHz through 135.95 MHz is allocated to civilian aviation voice communications.

VHF Frequency Utilization Plan

Time was when a pilot could travel anywhere in America with a few simple transmitting and receiving frequencies, but today's multiplying traffic congestion has created vast and complex radio telephony problems. To call a radio facility today a pilot must be able to select the right radio frequency—much like looking up the right number in a telephone directory. This information is available on aeronautical charts, the **VHF Chart Supplement** and the Transport Canada publication **Air Navigation Radio Aids.**

Within the band of VHF frequencies used by aviation, there are 720 individual frequencies that can be allocated by utilizing 25 KHz spacing. (For example: 119.000, 119.025, 119.050, 119.075, 119.100, 119.125, etc.)

Equipment capable of 25 KHz channel spacing is required in all aircraft operating in the High Level Airspace. For the present, aircraft operating in the Low Level Airspace require equipment capable of 50 KHz channel spacing (preferably) or 100 KHz spacing. Radio equipment capable of 50 KHz spacing can receive 360 individual frequencies. (For example: 119.05, 119.10, 119.15, 119.20, etc.) Equipment capable of only 100 KHz spacing can receive only 180 frequencies. (For example: 119.1, 119.2, 119.3, etc.)

The following are some of the most common VHF frequencies in use.

The universal VHF Emergency Frequency is 121.50 MHz.

For the most part, Private Advisory Stations (in Canada) transmit and receive on 122.8 MHz. Aeronautical Advisory Stations (in the U.S.) transmit and receive on 122.8 MHz at airports where there is no control tower, and on 123.0 MHz at airports that are served by a control tower. These frequencies are known as "UNICOM" and are used for communication between civil airplanes and ground based operators. Additional UNICOM frequencies are in the process of being assigned.

The frequency 122.2 MHz is used in Canada by DOT Aeradio Stations for both transmitting and receiving. In the United States, the frequency 122.2 MHz or 122.3 MHz is used by FAA Flight Service Stations to reply to private aircraft at controlled airports and 123.6 MHz at non-controlled airports.

Pilots operating in uncontrolled airspace are advised to remain continuously tuned to 122.2 MHz and (preferably) to use this frequency when calling DOT Aeradio Stations.

The frequency of 122.9 MHz has been allocated as the frequency to be used by civil airplanes for communications with other civil airplanes in the air.

The following listing of the allocation of VHF channels to the various aeronautical facilities under the Frequency Utilization Plan is relatively complete. However, changes in the Plan are made from time to time and are published in Transport Canada Information Circulars.

In the case of Air Navigation Aids (such as Omniranges, ILS Localizers, etc.) the frequencies are those on which the navigation signals are transmitted, and are also the frequencies on which stations with simultaneous voice facilities will reply to a call.

108.05 thru 117.95 MHz — Navigation Aids.

108.1 thru 111.9 MHz — ILS Localizers with simultaneous voice channel, operating on **odd** tenth decimal frequencies.

110.1 MHz — ILS Ramp Check.

112.1 thru 117.95 MHz — Omniranges (VOR).

114.8 and 115.7 MHz — VOR Ramp Check.

118.00 thru 119.65 and 119.75 thru 121.40 MHz — Air Traffic Control. Two-way.

119.70 MHz — Aircraft to Air Traffic Control. Below 12,000 ft.

121.50 MHz — Emergency. Air - Ground. The term "emergency" is used in a broad sense. In addition to actual distress, the frequency may be used (i) when communication on normal channels has failed, or (ii) when an airplane is not equipped with the normal frequencies required to call a particular ground station.

121.6 MHz — Search and Rescue.

121.6 thru 121.95 MHz — All aircraft and Air Traffic Control. Two-way. Airport Utility (Ground Control).

122.0 thru 122.30 MHz — All aircraft to Aeronautical Communications Stations. (Other than Towers and Company Stations).

122.2 MHz — All Airplanes to Aeradio Stations.

122.35 thru 122.75 and 122.85 thru 123.05 MHz — Non scheduled airplanes to Air Traffic Control.

112.80 MHz — Private Advisory Stations. Two-way. Air to Ground.

122.9 MHz — Private Advisory, air to air.

123.10 thru 123.55 MHz — Flight test and flying schools. Airplanes to company stations.

123.60 thru 126.65 MHz — Air Traffic Control.

126.2 MHz — Military Air Traffic Control. Two-way.

126.70 MHz — All civil airplanes to Aeradio or Flight Service Stations.

126.75 and 126.80 MHz — Air Traffic Control Communications. Below 24,000 ft.

126.9 MHz — Air - Ground. All airplanes to Aeradio Stations.

128.825 thru 132.025 MHz — Airplanes to Company Stations.

132.050 thru 134.95 MHz — Air Traffic Control. Above 24,000 ft.

135.00 thru 136.00 MHz — Airplanes to Company Stations.

135.85 thru 135.95 MHz — Flight Inspection.

135.9 MHz — Military Advisory.

Note: Because of the confusing number of VHF channels in use, and the frequent changes that are continually taking place, it is advisable when calling any Airway Communication Station, Control Tower or other facility, to state the frequency on which you expect them to reply.

ULTRA HIGH FREQUENCY

The UHF band includes the frequencies lying between 300 MHz and 3000 MHz. These frequencies are mostly allocated to special government use, except that Distance Measuring Equipment (DME) and the Glide Slope portion of ILS operate on frequencies in the UHF Band.

SINGLE AND DOUBLE CHANNEL COMMUNICATION

The radio equipment installed in airplanes is capable of both receiving and transmitting. In some cases, a transmission from the airplane is carried on one frequency and reception from the ground station is carried on another. In some cases, the same frequency is used for both transmitting and receiving.

SINGLE CHANNEL SIMPLEX means communication in one direction only at a time—transmitting and receiving on the same radio frequency.

DOUBLE CHANNEL SIMPLEX means transmitting on one channel frequency and receiving on another frequency—but not simultaneously.

DOUBLE CHANNEL DUPLEX means transmitting on one channel frequency and receiving on another frequency simultaneously.

CHARACTERISTICS OF RADIO SIGNALS

LOW, MEDIUM AND HIGH FREQUENCY

Waves emitted from a Low/Medium/High Frequency Transmitting Station are of two types (Fig. 4.).

Ground Waves follow the surface of the Earth.

Sky Waves travel up into the atmosphere and are reflected back to Earth from the **Ionosphere.**

Between the point where the ground waves end and the reflected waves strike the Earth there is a *"skip" Zone,* where very erratic signals or no signals at all are heard.

This characteristic of these signals accounts for the fact that sometimes you may hear a station, then lose it and later hear it again as you fly farther away from the station.

The behaviour of the sky waves is responsible for one of the chief advantages of HF radio — that of long range communication. It is possible on HF to communicate with a station 1000 miles away but at the same time be unable to reach a station 100 miles away.

Transmission capabilities of Low, Medium and High Frequency radio waves may vary by night and day. At night, the sky waves travel at a flatter angle, causing a skip zone of greater extent, but a signal distance far greater than during the day.

Transmissions are also affected by such things as sunspot activity or electromagnetic disturbances which can upset the reflecting ability of the Ionosphere. When this occurs, the radio waves are not reflected back to Earth, and a fade out is experienced.

Static is also a major problem in this frequency range.

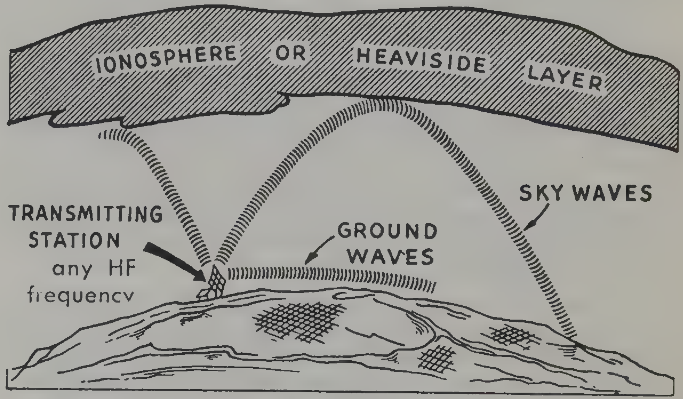

IONOSPHERE OR HEAVISIDE LAYER
SKY WAVES
TRANSMITTING STATION any HF frequency
GROUND WAVES

Fig. 4. Ground and Sky Waves.

VERY HIGH FREQUENCY

Very High Frequency radio waves have different properties entirely from the ground and sky waves described above. They do not "bounce" between the reflecting Ionosphere and Earth, but continue straight out into space. This means that they can only be received by an airplane on a **line of sight** position in relation to the station. VHF waves do not follow the curvature of the earth, nor bend around obstructions. For this reason, the higher the altitude at which the airplane is flying, the greater distance it will be able to receive VHF signals. (See Fig. 5.)

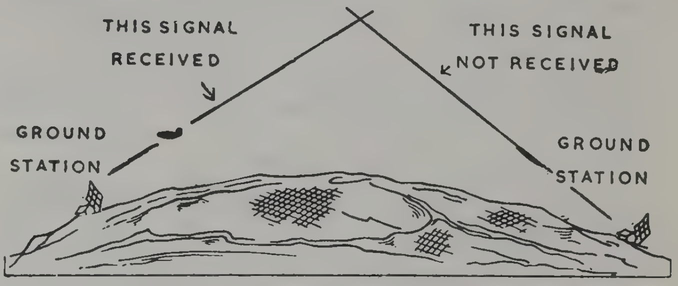


Fig. 5. Line of Sight Transmission.

Although line of sight transmission reduces the distance at which signals can be read at low altitude, this shortcoming is offset by the fact that stations below the horizon several hundred miles apart cannot interfere with one another.

VHF offers virtual freedom from atmospheric and precipitation static. Conversation is much like talking over an ordinary telephone. In addition to quiet, reliable communication, VHF equipment is smaller and lighter than corresponding L/MF equipment, and consequently less power is required for normal communication.

Table of VHF Reception Distance

Ht. Above Station	Reception Dist.	Ht. Above Station	Reception Dist.
1000 ft.	39 n.m.	10,000 ft.	122 n.m.
3000 ft.	69 n.m.	15,000 ft.	152 n.m.
5000 ft.	87 n.m.	20,000 ft.	174 n.m.

Fig. 6.

COMMUNICATION EQUIPMENT

To be fully capable of two-way communication with ground stations or other airborne stations, the radio equipment installed in an airplane must consist of a transmitter, a receiver, an antenna, a microphone and a speaker or headset. When the transmitter and receiver are combined in one control unit, it is known as a transceiver.

In transmitting, the spoken words of the pilot are picked up by the microphone and relayed to the transmitter where they are converted to radio signals. The radio signals are carried by a wire to the antenna where they are broadcast in all directions to be received by radio receivers in various radio ground and airborne stations.

In receiving, the antenna picks up a radio signal from a transmitting station, carries it by a wire to the aircraft receiver where it is converted to a voice signal and heard through the speaker or earphones.

Proper transmitting technique is to hold the microphone in the palm of the hand with the thumb resting lightly on the "press-to-talk" switch. Hold the microphone within one or two inches of the lips and press the microphone button. "Side tone" permits you to hear the sound of your own voice in the earphones and to monitor your transmission.

When finished speaking, you must release the button in order to receive. (The button automatically switches the set back to the receiver position.)

THE VHF TRANSCEIVER

Most modern VHF communication equipment is incorporated in a unit that also includes the VHF navigation equipment. Such a radio unit is known as a 1-1/2 system and is usually called a NAV/COM.

In the radio illustrated in Fig. 7, the communication equipment occupies the left side of the unit and is marked COM. It has Single Channel Simplex capability and 25 KHz spacing. It has crystal controlled tuning and an electronic display of the frequency selected.

Frequencies in the range from 118.000 to 135.975 MHz are tuned by the two large knobs. Volume is controlled by the small knob on the bottom right. The unit also includes a Squelch Control that eliminates undesirable noise.

To use the Squelch Control, turn the knob fully clockwise, then turn it back until the noise just ceases to be heard. Do not retard the squelch below this level at any time, as otherwise you may lose a weak signal which you desire to hear. In order to hear stations that are far off, it may be necessary to turn the squelch full on and put up with the noise to have the advantage of long distance communication.

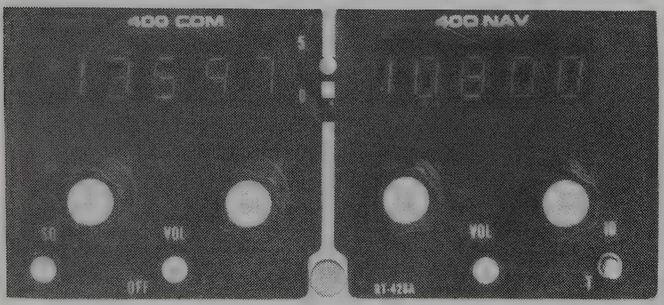


Fig. 7. VHF NAV/COM Radio Equipment.

THE HF TRANSCEIVER

The SunAir Radio illustrated in Fig. 8, which is typical of HF equipment, enables a pilot to communicate with stations in the Medium/High Frequency bands between 2 and 18 MHz (2000 and 18,000 KHz).

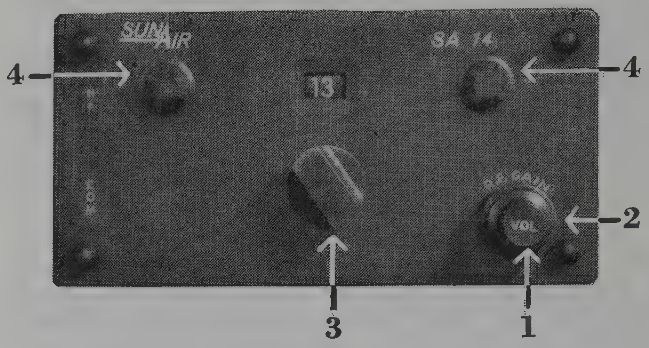


Fig. 8. SunAir M/HF Transceiver.

The Volume Control (1) is also the ON/OFF Switch. When the set is turned on, a high pitched sound can be heard in the head set indicating proper operation of the power supply.

The RF Gain Knob (2) is used to set the receiver according to the receiving conditions to achieve maximum sensitivity.

The Selector Switch (3) selects 14 different crystal controlled channels within the 2 to 18 Megahertz range. The set illustrated is switched to channel 13, which could be 5680 KHz or any other frequency within the frequency range.

Lamps (4) illuminate the set.

CARE OF AIRPLANE RADIO

Proper operation and care of airborne navigation and communication equipment is an important factor in maintaining its serviceability.

Here are a few good practices to follow:

1. Turn off all radios when starting the engines of the airplane. Large voltage transients are created during the start procedure and it is wise to protect radio equipment from these.

2. Do not turn a radio on and off repeatedly. Once it is turned on, keep it on for the entire time that it may be needed. Then turn it off.

3. Allow communication equipment to warm up for a minute or so before beginning a transmission. This practice is especially important for the older tube type of equipment.

4. When an airplane is flown at high altitudes and the equipment is mounted outside the heated areas, all radio units should be operated during the descent in order to reduce moisture condensation in the boxes. This practice is especially recommended with radar units in which high voltages are generated.

5. Incorrect voltage affects the operation of radios and can shorten component life. For this reason, it is wise to monitor airplane generator voltage on a periodic basis.

6. Be sure the airplane battery is maintained in good condition. This is especially important with the new solid state radios and airplane alternator systems.

7. When a problem does occur in the radio equipment, accurate description of the symptoms will assist the service man's diagnosis of the trouble.

RADIO COMMUNICATION FACILITIES

AUTOMATIC TERMINAL INFORMATION SERVICE (ATIS)

Non-control information relating to ceiling, visibility, wind, runway in use, NOTAMS affecting the airport, etc, is continuously broadcast on the Automatic Terminal Information Service. The information is recorded by tower personnel and is broadcast on the voice facility of the VHF Omni-directional range or, in some cases, on a specially assigned VHF/UHF channel.

Each recording is identified by a phonetic alphabet code letter, beginning each day with "Alfa". As airport conditions, such as wind, altimeter setting, etc., change, a new tape is prepared. Each succeeding message is given a new identifying letter, i.e., Bravo, Charlie, etc. A typical ATIS message might be:

> **Vancouver International Airport. Information Bravo. Vancouver Weather is Three Thousand Scattered, Measured Ceiling Five Thousand Overcast. Visibility Ten. Haze. Temperature One Five. Dew Point Eight. Wind Two Five Zero at Ten. Altimeter Two Niner Niner Eight. Runway Two Six. Inform Vancouver ATC on Initial Contact that you have received Information Bravo.**

The tower controller then does not have to issue this information in his message to you.

During periods of rapidly changing conditions which would create difficulties in keeping the ATIS message current, the following message will be recorded and broadcast:

> **Because of rapidly changing weather and airport conditions, contact ATC for current information.**

The word CAVOK (kay-oh-kay) is used in ATIS messages to denote a weather condition in which visibility is 6 miles (10 kilometers) or more, there are no clouds below 5000 feet (1500 meters) and no precipitation, thunderstorms, shallow fog or drifting snow.

The ATIS service is in operation at most of the major international airports. Information on the frequency on which the ATIS is broadcast is printed on aeronautical charts and also in the **VFR Chart Supplement.**

CONTROL TOWER

Many airports have the service of a Control Tower to ensure the efficient and safe movement of air traffic. The air traffic controllers in the Tower are responsible for the control of all traffic, taking off and landing, and for the control of all VFR traffic within the Positive Control Zone surrounding the airport.

The radio frequency on which the Tower operates can be found on aeronautical charts in the aerodrome information and in the **VFR Chart Supplement.** As well as the primary frequency on which the Tower both transmits and receives, there are other frequencies on which the Tower transmits and/or receives. Towers always monitor 122.50 MHz, for example. Aircraft without the capability of Single Channel Simplex can transmit on this latter frequency and receive on the primary Tower frequency.

GROUND CONTROL

Some controlled airports also have Ground Control. The ground controller is responsible for the movement of all traffic on the ground at the airport, except aircraft landing and taking off.

The ground controller operates on a special frequency allocated for that purpose. At most airports, that frequency is 121.9 MHz, although other frequencies in the range 121.7 through 121.9 MHz are used if there is a possibility of interference with another ground controller at a nearby airport.

The Ground Control frequency in use at any particular airport is published in the **VFR Chart Supplement.**

Ground controllers will provide the pilot with precise taxi instructions and information about services and facilities.

RAMP CONTROL

At very busy airports where there is a lot of ground traffic in the vicinity of the terminal, Ramp Control Service is sometimes provided. The ground controller will clear an aircraft to a general parking area and then advise the pilot to contact the ramp controller for explicit instructions as to where to park. The ramp controller operates on his own assigned frequency.

TERMINAL ARRIVAL AND DEPARTURE CONTROL

Arrival Control is provided to expedite the flow of IFR flights inbound within a Terminal Control Area.

Departure Control provides the same service for outbound IFR flights.

The frequencies for Arrival and Departure Control for particular airports are listed in the **IFR Chart Supplement** and in the **Canada Air Pilot.**

Most Arrival and Departure Control units are equipped with radar surveillance scopes, or scanning screens, which give the controller the range and azimuth of every airplane in the vicinity. Controllers are therefore able to issue any necessary instructions for the maintenance of safe separation and the avoidance of collision hazards. These facilities are purely *traffic control services,* and should not be confused with GCA, which provides instrument glide path landing *guidance.* They do, however, give position information and will furnish a lost pilot with his distance and the magnetic heading to the airport. They will also furnish the wind speed, the runway in use and pertinent traffic information.

Although Arrival and Departure Control is principally in operation to handle IFR traffic, at some busy airports arriving and departing VFR traffic is also handled by this facility. In such a case, the pilot is instructed by an Air Traffic Control Unit or in the ATIS information to contact Arrival or Departure Control on the assigned frequency.

Arriving VFR airplanes may contact Arrival Control on their own initiative and request **Radar Assistance** if they wish to do so. It is important to make the call at a reasonable distance from the facility and state your position as accurately as possible to assist the controller in locating you on the radar scope. Remain in communication with Arrival Control until advised to contact the Tower.

Departing VFR traffic may also contact Departure Control for **Radar Assistance.** The request should be made on initial contact with Ground Control and information as to the direction of the flight should be given. The Tower will advise when to contact Departure Control. Departure Control takes over when the aircraft clears the runway on take-off and vectors★ it on radar until it is established on a course along the appropriate navigation facility.

★ *Vectors are defined in the Chapter on Air Navigation. In Radar Advisory service the term has acquired a new meaning and is used to designate Headings given to pilots to steer (for the purpose of avoiding other traffic, or for detouring around thunderstorms). A radar traffic controller giving steering instructions to an aircraft is said to be "vectoring" the aircraft.*

TERMINAL RADAR SERVICE AREAS (TRSA)

Terminal Radar Service Areas are in operation at some major airports in Canada. Where they are in operation, the VFR pilot is required to contact the TRSA controller on the assigned frequency prior to entering the TRSA. The TRSA controller will then vector the aircraft to the airport and at the appropriate time advise the pilot to switch to the Tower frequency for landing instructions.

The TRSA frequencies are listed on the special TRSA charts.

VHF DIRECTION FINDING SERVICE

At many airports, VHF Direction Finding equipment is now in operation. This facility enables an Aeradio Station or Control Tower operator to advise a pilot of his bearing from the airport. DF information is electronically derived from radio signals transmitted from the aircraft. It operates normally on the facility's primary air/ground frequency. Two factors limit the provision of the service. Since VHF transmissions are restricted to line-of-sight, altitude and location are a factor. Secondly, power of the transmitted signal will affect reception. Information may be obtained from either a speech transmission or a transmission in which there is no speech, only the mike button pressed.

DF service is provided when requested by the pilot or at the suggestion of ATC. The pilot requesting DF service should provide the facility with the following information: position of aircraft, present heading and altitude.

Aircraft: **Ottawa Tower — This is Foxtrot Romeo Tango Mike — Request DF Homing — Approximately Two Zero Miles South of Ottawa — Heading Zero Four Five — Seven Thousand.**

The pilot will then be given the headings required to "home" to the airport at which the DF equipment is installed.

Tower: **Foxtrot Romeo Tango Mike — This is Ottawa Tower — For Homing to Ottawa International — Steer Heading Zero One Five.**

AERADIO STATIONS

Aeradio Station is a term applied to the DOT communication stations operating along the air routes in Canada. Most of these stations are associated with airports, both large and small. In the United States, these are called Flight Service Stations and they supply identical services.

There are more than one hundred of these stations in Canada operated by personnel trained to provide an efficient flight safety service to pilots.

Aeradio Station communications with aircraft are conducted on a standard set of frequencies, including the emergency channel 121.5 MHz, the general purpose channel 126.7 MHz and the advisory channel 122.2 MHz. Most stations have 122.1 MHz (receive only), and a number of the more northerly stations have 5680 KHz.

During their hours of operation, these channels are continuously monitored except for a brief period from 6 minutes before to 5 minutes after the hour. During this 11 minute period, the aeradio operator is recording the hourly weather observation that must be made at some stations.

Aeradio Stations, located at airports without control towers and at controlled airports when the control tower is not in operation, provide an **Airport Advisory Service** to arriving and departing aircraft. A landing or take off advisory may include wind direction and velocity, the favoured runway, ceiling and visibility, altimeter setting, pertinent NOTAMs, airport conditions, such as snow on the runway, braking action, obstructions or any known hazards. The Airport Advisory Service does not exercise actual traffic control but will advise of known or observed traffic for the information of pilots.

They also provide **Flight Advisory Services,** relaying ATC clearances and other instructions, acceptance of Flight Plans and Flight Notifications for relay to ATC, provision of weather reports and forecasts, information on the status of navigation aids, communications facilities and airports, handling aircraft position reports and PIREPS.

Aeradio Stations make regular **Broadcasts** of the latest weather reports for key locations in the general station area. Pertinent changes in weather conditions are broadcast as soon as they are issued. Regular broadcasts contain any valid PIREPS and SIGMETS.

They provide **Pre-Flight Assistance,** having available weather information and other (non-weather) aeronautical information.

Aeradio Stations are connected to ATC Centres by direct phone lines in most cases, permitting quick access to centre facilities for those aircraft requiring in-flight instructions when flight paths do not permit radio contact with ATC units.

PERIPHERAL STATIONS

Where difficult communication conditions prevail, remote transmitting and receiving facilities have been established. These Peripheral Communication Stations (PAL) are operated from the nearest Aeradio Station. Aircraft in the general area of the PAL Station can therefore communicate directly with an ATC Centre which may be hundreds of miles away. The Peripheral Station is connected by land lines with the ATC Centre. The remote services of a PAL Station can vary from a single VHF channel to the full standard aeradio complement.

RADAR ADVISORY SERVICE

Radar Advisory Navigation Assistance is available from certain ATC units. As long as the aircraft is operating within areas of radar and communication coverage and can be radar identified, the ATC facility will provide assistance to navigation in the form of position information, vectors or track and groundspeed checks, information about traffic in proximity to the flight path of the aircraft and about weather phenomena such as thunderstorms.

In advising of the existence of other traffic, the ATC unit uses the positions of the clock to indicate the whereabouts of these other aircraft.

For example: **Traffic at 3 O'Clock.**

FLIGHT INFORMATION SERVICE

Flight Information Service is provided by Air Traffic Control units to provide pilots with information about hazardous flight conditions. Such data would include information about conditions and hazards which was not available at the time of take off or which may have developed along the route of flight.

Flight Information Service is provided whenever practicable to any aircraft in communication with an Air Traffic Control unit either prior to flight or when in flight.

VFR flights are provided with information concerning severe weather conditions along the proposed route of flight, changes in serviceability of navigation aids, conditions of airports and associated facilities and other items considered pertinent to the safety of flight.

Flight Information messages are intended as information only. If a specific action is suggested, the pilot is responsible for making the final decision concerning the suggestion.

RADIO TELEPHONE PROCEDURE

Correct procedure on the part of operators of radiotelephone equipment is necessary for the efficient exchange of communications and is particularly important where lives and property are at stake. It is also essential for a fair sharing of "On the Air" time in the crowded radio spectrum.

Radiotelephone equipment installed in any civil aircraft may be operated only by persons holding an appropriate radio operator's licence — Radiotelephone Operator's Restricted Certificate. A reciprocal agreement between Canada and the U.S.A. permits citizens of either country to operate radio equipment installed in aircraft registered in either country if the operator holds a valid Canadian or U.S. pilot's licence and a valid Canadian or U.S. radio operator's licence.

PHRASEOLOGY

Standard phraseology is recommended in the interest of clarity and brevity. It is not compulsory for a pilot to use these standard phrases. If you wish to communicate with a radio facility in your own words, by all means do so. However, use of the standard phrases does provide a uniformity in transmission; it makes your transmissions more readily understood by the ground station operators and enables you to understand more easily transmissions to you.

GROUND STATIONS

Ground radio facilities are identfied by their names. For example:

APPROACH	— ATC Approach Control
ARRIVAL	— ATC Arrival Control
CENTRE	— Area Control Centre
CLEARANCE DELIVERY	— IFR Clearance Delivery
DEPARTURE	— ATC Departure Control
G C A	— Ground Controlled Approach System
GROUND CONTROL	— Airport Ground Control
INFORMATION	— Flight Information Centre
PRECISION RADAR	— Precision Radar Approach Facility
RADAR	— Enroute Radar Facility
RADIO	— Aeronautical Ground Communication Station
SURVEILLANCE RADAR	— Surveillance Approach Radar Facility
TERMINAL	— Terminal Control Unit
TOWER	— Airport Control Tower

In calling a particular facility, a pilot would use the name of the station followed by the facility he is contacting.

For example: **Winnipeg Approach. This is Piper FTRS**
Vancouver Centre. This is Piper FTRS
Calgary Ground Control. This is Piper FTRS
Cleveland GCA. This is Piper FTRS
Joliet OMNI. This is Piper FTRS
Ottawa Tower. This is Piper FTRS

NUMBERS

Numbers are pronounced as follows:

0 ZEE-RO	5 FIFE	Decimal
1 WUN	6 SIX	DAY-SEE-MAL
2 TOO	7 SEV-en	Thousand
3 TREE	8 AIT	TOU-SAND
4 FOW-er	9 NIN-er	

When referring to numbers, each digit is stated separately.

For example: Ten is spoken **One Zero.**
Nineteen is spoken **One Niner.**

PHONETIC ALPHABET

To avoid confusion due to similarity in sound of some letters of the alphabet (such as "B" and "C") a phonetic alphabet has been devised. It is not compulsory, but advisable to use it when calling the registration of your airplane.

For example: GFEM is spoken **Golf Foxtrot Echo Mike.**

Once having definitely established your identity on the first call-up, and had it confirmed back, it is then no longer necessary to continue the use of these rather cumbersome two-syllable words. You may subsequently find it more convenient to refer to your registration letter as GFEM ("gee-eff-ee-em").

A Alfa
B Bravo "BRAH-voe"
C Charlie
D Delta
E Echo
F Foxtrot
G Golf
H Hotel
I India
J Juliet "Jool-ee-YET"
K Kilo "KEE-loe"
L Lima "LEE-mah"
M Mike
N November
O Oscar
P Papa "POP-ah"
Q Quebec "KAY-BECK"
R Romeo
S Sierra
T Tango
U Uniform
V Victor
W Whiskey
X X-Ray
Y Yankee
Z Zulu

TIME

The 24 hour system is used in expressing time. It is expressed by four figures, the first two denoting the hour past midnight and the last two the minutes past the hour.

For example: 12:00 midnight is expressed — 0000
12:30 a.m. " " — 0030
2:15 a.m. " " — 0215
5:45 a.m. " " — 0545
12:00 noon " " — 1200
3:30 p.m. " " — 1530
10:50 p.m. " " — 2250

Normally Greenwich Mean Time (GMT) is used. In fact, all Air Traffic Control facilities in North America operate on GMT. The letter "Z" after the hour indicates GMT.

Where operations are conducted solely within one time zone, standard zone time may be used, if care is taken to indicate clearly the time zone. Daylight Saving Time is not used. Standard time zones are indicated by letters as follows:

Newfoundland	—	N
Atlantic	—	A
Eastern	—	E
Central	—	C
Mountain	—	M
Pacific	—	P
Yukon	—	Y

For example: 2:15 p.m. EST is expressed 1415 E
9:00 a.m. PST is expressed 0900 P
11:45 p.m. GMT is expressed 2345 Z

In Air Traffic Control procedure, the hour is often omitted, and the time referred to in minutes past the hour only.

For example: 10:25 would be referred to as 25 and spoken **Two Five.**

However, if the hour is included in the time, it is spoken in four digits.

For example: 8:45 a.m. is spoken **Zero Eight Four Five.**
12:30 a.m. is spoken **Zero Zero Three Zero.**
2:45 p.m. is spoken **One Four Three Five.**

FLIGHT ALTITUDES

Flight altitudes are always given in thousands and hundreds of feet above sea level.

For example: **One Thousand.** (1000 feet ASL)
Two Thousand Five Hundred . (2500 feet ASL)

One Zero Thousand. (10,000 feet ASL)
One Six Thousand. (16,000 feet ASL)
Flight Level Two Four Zero. (FL 240)

RADIO FREQUENCIES

Radio frequencies are referred to as follows:

For example: 121.5 MHz is spoken as **One Two One Decimal Five Megahertz.**

It is necessary that the pilot on his initial call state the frequency on which he is transmitting. This procedure is required in order to provide the ground station communicators, who guard many frequencies, with a positive indication of the correct transmitter to be selected for answering the call.

The ground station will normally reply on the frequency on which the call is received. Calls received on 122.2 MHz will be answered on the navigational aid frequency. Pilots requiring an exception to this procedure should state the frequency on which the reply is expected.

Aircraft: **Vancouver Radio This is Beechcraft Foxtrot Delta Lima Tango — On One Two Two Decimal Two — Over.**

The ground station will reply on the navigational aid frequency.

Aircraft: **Ottawa Radio This is Piper Foxtrot Alfa Golf Lima — On One Two Two Decimal Two — Reply on One Two Six Decimal Seven — Over.**

The ground station will reply on 126.7 MHz.

Aircraft: **Montreal Radio — This is Cessna Golf Bravo Romeo Yankee — On One Two Six Decimal Seven — Over.**

The ground station will reply on 126.7 MHz.

THE MORSE INTERNATIONAL CODE

It is not necessary for a pilot to know Morse Code in order to use aeronautical radio facilities. However, the identifiers of VOR stations, ILS Localizers and Non Directional Beacons are broadcast in Morse Code and it is therefore advantageous to have some knowledge of the code.

A	· —	N	— ·	1	· — — — —
B	— · · ·	O	— — —	2	· · — — —
C	— · — ·	P	· — — ·	3	· · · — —
D	— · ·	Q	— — · —	4	· · · · —
E	·	R	· — ·	5	· · · · ·
F	· · — ·	S	· · ·	6	— · · · ·
G	— — ·	T	—	7	— — · · ·
H	· · · ·	U	· · —	8	— — — · ·
I	· ·	V	· · · —	9	— — — — ·
J	· — — —	W	· — —	0	— — — — —
K	— · —	X	— · · —		
L	· — · ·	Y	— · — —		
M	— —	Z	— — · ·		

STANDARD PHRASES

The following phrases and words should be used whenever applicable:

Word or Phrase	Meaning
Acknowledge	"Let me know you have received and understood this message."
Affirmative	"Yes."
Break	"I hereby indicate the separation between portions of the message."
Confirm	"My version is . . . Is that correct?"
Correction	"I have made an error. The correct version is . . . "
Do you read?	"I have called you more than once. If you are receiving me, reply."
Go Ahead	"Proceed with your message."
How do you read me?	Self explanatory
I say again	"I will repeat."
Negative	"No."
Out	"My transmission is ended. I do not expect a reply from you."
Over	"My transmission is ended. I expect a reply from you."
Read back	"Repeat this message back to me after I have given 'Over'."
Roger	"Okay. I have received your message."
Say again	"Repeat." **Never use the word "Repeat" — it is reserved for military purposes.**
Speak slower	Self explanatory
Stand by	"I must pause for a few seconds." If the pause is to be longer than a few seconds, add "Out".
That is correct	Self explanatory
Verify	"Check with the originator."
Wilco	"Your instructions received, understood, and will be complied with."
Words twice	"Communication is difficult. Please send every phrase twice." or "I will send every phrase twice."

PRIORITY OF COMMUNICATION

In general, the following priorities are applied to radio communications by Aeradio Stations.

1. Emergency communications (Distress and Urgency)
2. Flight Safety communications (ATC clearances, airport advisories, position reports, airfile Flight Plans, etc.)
3. Scheduled broadcasts
4. Unscheduled broadcasts
5. Other air-ground communications (Meteorological messages, flight regularity messages)

NOTAM, SIGMET or PIREP messages are generally handled as priority item 4.

GOOD RADIO TECHNIQUE

Optimum use of aircraft radio communication facilities depends on the good technique of the operator.

It is good procedure for the pilot to listen briefly on the channel to be used before transmitting to ensure that he will not interrupt or cause harmful interference to stations already in communication. Make calls as brief as possible and avoid calling Aeradio Stations at or during scheduled broadcast periods whenever possible.

1. Pronounce words clearly. Do not slur sounds or run words together.
2. Speak at a moderate rate, neither too fast nor too slow.
3. Keep the pitch of the voice constant. High pitched voices transmit better than low pitched voices.
4. Do not shout into the microphone.
5. Hold the microphone in the correct position — about 1 inch from the lips.
6. Know what you are going to say before starting the communication. "Ums" and "ahs" take up valuable air time.
7. Acknowledge receipt of all ATC messages directed to and received by you. The acknowledgement should take the form of a transmission of the aircraft call sign, or the call sign followed by an appropriate message. Clicking your microphone button as a form of acknowledgement is not proper radio procedure.
8. Profanity or offensive language is not permitted.
9. Do not request transportation, accommodation or other personal services from airways communication stations. They will not accept such messages.

COMMUNICATION CHECKS

Aircraft operators may sometimes wish to check the serviceability of their communication equipment. Such a check may be made while the aircraft is airborne (Signal Check), while the aircraft is about to depart (Preflight Check), or by ground maintenance personnel (Maintenance Check).

The readability scale employed for communications checks has the following meaning: 1. Unreadable. 2. Readable now and then. 3. Readable with difficulty. 4. Readable. 5. Perfectly readable.

Aircraft: **Winnipeg Radio This is Piper Foxtrot Romeo Yankee Tango — Signal Check on Five Six Eight Zero — Over.**

Tower: **Piper FYRT This is Winnipeg Radio — Signal Check Reading You Five — Over.**

PORTABLE RADIO INTERFERENCE

Portable radio and television receivers (FM, AM and TV) produce radiation which causes interference with aircraft radio navigation equipment. Do not operate, or permit anyone to operate this type of equipment when VOR or ILS radio receivers are in use.

RADIO TELEPHONE PROCEDURES IN COMMUNICATION WITH GROUND STATIONS

CALL-UP AND TAXI CLEARANCE

Call the Tower and ask for permission to taxi. This should be done on the Ground Control frequencies 121.9, 121.7 MHz etc. Always state the frequency on which you are calling and/or expect a reply. Do not leave the ramp until cleared by the controller to do so. Ground Control will reply, clearing you to the runway in use and will give you the surface wind, the altimeter setting and the time.

Aircraft: **Norwood Ground Control — This is Cessna Foxtrot Mike Kilo Alfa — Preflight Check — One Two One Decimal Niner (1) — Over.**

(1) Meaning you expect a preflight check on 121.9 Megahertz.

Ground: **Cessna Foxtrot Mike Kilo Alfa — This is Norwood Ground Control — Radio Checks (2).**

(2) Instead of *"Radio Checks"*, Ground Control may reply as follows: *"Read You" (1) Bad (2) Poor (3) Fair (4) Good (5) Excellent"*

Aircraft: **Norwood Ground Control — Cessna MKA (3) on West Ramp — VFR to Forestville — Taxi Instructions — Over.**

(3) After communication has been established, the aircraft registration may be abbreviated to the last three letters in the case of Canadian registered aircraft. In the case of foreign aircraft, the registration may be abbreviated to the first and last three characters. For example, N 5768Q may be abbreviated to N68Q.

Ground: **Cessna MKA — Cleared to Runway Two Seven (4) — Wind Two Seven Zero at One Zero (5) — Altimeter Two Niner Seven Five (6) — Time Zero Five (7).**

(4) Runway 27 lies approximately 270° Magnetic. Your compass or directional gyro should therefore read 270° when you line up for take-off.

(5) The wind is west at 10 kts. Winds given by Control Towers are magnetic whereas those given by Meterorological Stations are true.

(6) Set the Barometric Scale on your altimeter to 29.75.

(7) Set your clock to 05 minutes past the hour.

With the increasing traffic around all airports, frequency congestion is becoming a problem and brevity in your transmissions is therefore desirable.

At many major airports, information about ceiling, visibility, runway in use, etc. is given over the Automatic Terminal Information Service. Listen to this information and when first calling Ground Control, state that you have the information broadcast on ATIS.

At an airport where there is no ATIS, listen on the Ground Control frequency to the controller talking to other airplanes and take note of the "numbers". When making your first contact, inform the controller:

Aircraft: **Norwood Ground Control — Cessna Foxtrot Mike Kilo Alfa with the Numbers** — etc. etc.

The controller then does not have to take up valuable air time repeating information that you already know.

If cleared to taxi to the runway in use, no further clearance is required to cross any runway enroute. If for any reason the airport ground controller requires that you request a further clearance before crossing or entering any runway enroute, he will so advise you. For example:

Ground: **Hold Short of Runway 14 until advised to proceed.**

A clearance to taxi "to" the runway in use is not however a clearance to taxi "on" the assigned runway. You must hold short of the runway until receiving a clearance to taxi on the runway to take-off position.

FLIGHT PLAN

If you have not previously filed a Flight Plan, you may file one giving the information over the radio. However, filing a Flight Plan by radio is only permissible when it is **impossible** to file one in person or by telephone. A long transmission such as the filing of a Flight Plan aggravates the congestion of the air-ground communication channels and ties up controllers whose job is to expedite the safe and orderly movement of traffic.

Aircraft: **Summit Tower — This is Piper Foxtrot Papa Tango Victor — Here is my Flight Plan — Summit — Eight Thousand VFR (1) via Victor Seven to Huntington — Departing at One Three — Airspeed One Zero Five Knots — Elapsed Time One Hour Plus Four Minutes — Fuel on Board Two Hours Plus Ten Minutes — Standard VHF Radio — Transponder Equipped — Garrett ELT — Two Persons on Board — Pilot Ayer Worthy — Over.**

Tower: **FPTV — I have your Flight Plan.**

Aircraft: **Roger PTV.**

(1) VFR, Visual Flight Rules, do not require any stated altitude. However, Air Traffic Control strongly recommend that you state your altitude and route. "Eight thousand" means 8000 feet altitude. "Victor Seven" means that you will fly via VOR Airway V7.

TAKE OFF CLEARANCE

When you have run up your engine(s) and made your cockpit check, if you have not already done so, change to Tower frequency and request a clearance for take-off:

Aircraft: **Moncton Tower — Stinson Foxtrot November November Charlie — Ready for Take off (or Ready to Roll).**

Tower: **Stinson November November Charlie — Cleared for Take off.**

Aircraft: **Roger NNC.**

SPECIAL CLEARANCE

Should you wish to execute some special maneuver, such as a right-hand turn after taking off, the following phraseology would be appropriate:

Aircraft: **Bonanza Golf Alfa Tango Hotel — Ready for Take off — Request Right Turn Out — Over.**

Tower: **Bonanza Alfa Tango Hotel — Right Turn Approved — Cleared for Take off.**

Aircraft: **Roger ATH.**

After take-off, remain tuned to the Tower frequency. The Tower will usually call you after take-off, give you any necessary traffic information, your time off, and a clearance from the Tower frequency. (Airplanes doing local flying will remain tuned to the Tower frequency at all times.)

After take-off, you may request clearance from the Tower frequency to another service that is appropriate. VFR flights, however, will not be released from the Tower frequency while operating within the Control Zone.

Tower: **Bonanza Golf Alfa Tango Hotel — Off at One Five — Cleared Tower Frequency.**
Aircraft: **Alfa Tango Hotel — Roger Out.**

VFR POSITION REPORTS

An airplane flying Visual Flight Rules is not required to report its position to intermediate stations enroute. However, it is a good idea to do so and there is a special sequence to follow in making this report. After calling the Aeradio Station and receiving their acknowledgement of your call, you should state your wish to give a report on your position. The sequence of this report is as follows:

1. Identification
2. Position
3. Time
4. Altitude
5. VFR Flight Plan
6. Destination
*7. Track true
*8. Groundspeed
*9. Fuel

*Required only for off airways flights in Alaska and overwater flights in Oceanic Areas.

Aircraft: **Ottawa Radio — This is Cessna Golf Delta Delta India — VFR Position Report — Over.**
Station: **DDI This is Ottawa Radio — Go Ahead.**
Aircraft: **Ottawa Radio — DDI by Ottawa at Five Eight — Four Thousand VFR — Estimating Killaloe One Two Three Four — Muskoka Next.**

ENROUTE REPORTS (CONTROLLED VFR)

In Canada, Controlled VFR is *compulsory* "on airways" at or above 9500 ft. (12,500 ft. west of the Rockies). Airplanes flying *Controlled VFR* must obtain air traffic clearances and file en route position reports at all compulsory reporting points, or other reporting points which may be specified by ATC.

It is a good idea to keep a pencil and paper handy to copy down the clearances. The following shorthand symbols, used by ATC controllers, may prove useful to you:

Words and Phrases	Shorthand
ABOVE	ABV
ADVISE	ADV
AFTER (PASSING)	<
AIRPORT	A
ALTERNATE INSTRUCTIONS	( )
ALTITUDE 6,000-17,000	60-170
AND	&
APPROACH	AP
FINAL	F
LOW FREQUENCY RANGE	R
OMNI	O
PRECISION	PAR
STRAIGHT-IN	SI
SURVEILLANCE	ASR
APPROACH CONTROL	APC
AT (USUALLY OMITTED)	
(ATC) ADVISES	CA
(ATC) CLEARS OR CLEARED	C
(ATC) REQUESTS	CR
BEARING	BEAR
BEFORE	>
BELOW	BLO
BOUND	B
EASTBOUND, etc.	EB
OUTBOUND	OB
INBOUND	IB
CLIMB (TO)	↑
CONTACT	CT
COURSE	CRS
CROSS	X
CROSS CIVIL AIRWAYS	≠
CRUISE	→
DELAY INDEFINITE	DLI
DEPART	DEP
DESCEND (TO)	↓
DIRECT	DR
EACH	ea
EXPECT APPROACH CLEARANCE	EAC
EXPECT FURTHER CLEARANCE	EFC
FAN MARKER	FM
FLIGHT PLANNED ROUTE	FPR
FOR FURTHER CLEARANCE	FFC
FOR FURTHER HEADINGS	FFH
HEADING	HDG
HOLD (DIRECTION)	H-W
INTERSECTION	XN
(ILS) LOCALIZER	L
OMNI (RANGES)	O
OUTER COMPASS LOCATOR	LOM
OUTER MARKER	OM
RADAR VECTOR	R V
RADIAL	RAD
RANGE (LF/MF)	R
REMAIN WELL TO LEFT SIDE	LS
REMAIN WELL TO RIGHT SIDE	RS
REPORT DEPARTING	RD
REPORT LEAVING	RL
REPORT ON COURSE	R-CRS
REPORT OVER	RO
REPORT PASSING	RP
REPORT REACHING	RR
REPORT STARTING PROCEDURE TURN	RSPT
REQUEST ALTITUDE CHANGES ENROUTE	RACE
REVERSE COURSE	RC
RUNWAY	RY
STANDBY	STBY
TAKEOFF (DIRECTION)	T → N
TOWER	Z
TRACK	TR
TURN LEFT	LT
TURN RIGHT	RT
UNTIL FURTHER ADVISED	UFA
VICTOR	V

For example: C FTOM BLT/V5 M5/UXB

Means: ATC clears Foxtrot Tango Oscar Mike to Bolton via Victor 5. Climb to 5000 feet immediately and maintain 5000 until reaching Uxbridge Reporting Point.

You have filed a Flight Plan from Yarmouth Nova Scotia for a flight to St. Johns (Torbay) Nfld., controlled VFR, at 11,000 ft. via Victor Airway 312. Compulsory reporting points along the way are: Halifax, Copper Lake, Sydney and Atlantic. Your airplane is fitted with a VHF transceiver and an Omnirange receiver. (Maximum line-of-sight reception distance at 11,000' is 128 n.miles, so some of the latter portion of your flight will be by D/R navigation). You have taken off at 19.15 Z and are climbing to your intended altitude. You contact Yarmouth Radio for a clearance (from Moncton Centre) to enter the Block Airspace.

Note: *All clearance reports you make are to the Air Traffic Control Centre (ATC) but may be made through a Communications Facility such as a Tower, Aeradio or Omni Range Station, etc. The Communications Facility relays your message to ATC and issues the clearance to you. (When you report to a PAL (Peripheral) Station, however, you are in effect in direct communication with the Centre by remote control).*

Aircraft: **Yarmouth Radio — This is Twin Comanche Golf Kilo Tango Mike — One Two Two Decimal Two** (listening on Omni Frequency) **— Over.**
Station: **Golf Kilo Tango Mike — This is Yarmouth Radio — Go Ahead.**
Aircraft: **KTM at Eight Thousand Five Hundred — Two Zero Miles East on Victor Three One Two (1) — Requesting Eleven Thousand Controlled VFR to Torbay via Victor Three One Two — Over.**

(1) Meaning the 080° radial of the Yarmouth Omnirange which provides the outbound track for Victor Airway 312.

Station: **ATC Clears KTM to Torbay via Victor Three One Two — Climb to and Maintain Eleven Thousand VFR — Report Reaching Eleven Thousand — Over.**
Aircraft: (Repeats clearance back) **KTM is cleared to Torbay via Victor Three One Two — Climb to and Maintain Eleven Thousand VFR — Report Reaching Eleven Thousand — Over.**
Station: **Roger Yarmouth Radio Out.**

You report on reaching 11,000 feet as instructed.

Aircraft: **Yarmouth Radio — This is GKTM at Eleven Thousand at Two Two (2) — Over.**

(2) Meaning at 22 minutes past the hour, i.e.: 19.22 GMT.

Station: **GKTM — This is Yarmouth Radio — Check you at Eleven Thousand at Two Two — Over.**
Aircraft: **KTM.**

When you arrive over the Halifax Omnirange (your first reporting point) you check the time, calculate your groundspeed and your estimated time of arrival over the next reporting point. You have contacted Halifax Radio and the station has acknowledged your call.

Aircraft: **GKTM over Halifax at One Five — Eleven Thousand — VFR — Estimating Copper Lake (3) at Two Zero Four Zero — Sydney (4) — Over.**

(3) Your next reporting point.
(4) The next succeeding reporting point.

Station: **Check you over Halifax at One Five — Eleven Thousand — VFR — Estimating Copper Lake at Four Zero — Over.**
Aircraft: **KTM.**

You tune in the Charlottetown VOR on 114.1 MHz and select 162° on your Omni Bearing Selector. This is the 162° radial of the Charlottetown Omnirange. Where it intersects

Victor Airway 312 is the Copper Lake reporting point. When your needle centres, you are over Copper Lake.

Aircraft: **Sydney Radio — This is Twin Comanche Golf Kilo Tango Mike — One Two Two Decimal One — Over.**

If the station does not reply immediately,

Aircraft: **Sydney Radio — This is Twin Comanche Golf Kilo Tango Mike — One Two Two Decimal One — Do you read? — Listening on One One Four Decimal Niner — Over.**

If a station does not answer you after two or more calls have been made, you may issue a general call, requesting any station hearing you to contact the station you are calling. For example:

Aircraft: **Any Station receiving me — Any Station receiving me — This is Golf Kilo Tango Mike — Advise Sydney Radio I am calling him on One Two Two Decimal One — Listening on One One Four Decimal Niner — KTM Out.**

When contact with the station has been established.

Aircraft: **Over Copper Lake at Four Zero — Eleven Thousand — VFR — Estimating Sydney at Two One One Five — Atlantic — Over.**

Station: **Check you over Copper Lake at Four Zero — Eleven Thousand — VFR — Estimating Sydney at Two One One Five — Atlantic — Sydney Altimeter Two Niner Seven Five** (and any other information considered necessary, such as the weather ahead, etc.) **— Over.**

Aircraft: **Roger KTM.**

You arrive over Sydney at 21.15 and decide to request permission to descend below Block Airspace. You have contacted the station and he has acknowledged your call.

Aircraft: **By Sydney at One Five — Eleven Thousand — VFR — Estimating Atlantic at Two One Five Two — Requesting Descent Below Nine Thousand Five Hundred — Over.**

On account of traffic, or for some other reason, your request cannot be immediately approved.

Station: **GKTM Maintain Eleven Thousand — Report Atlantic for Further Clearance — Call Five Minutes West of Atlantic — Over.**

Aircraft: (repeats clearance) **KTM maintaining Eleven Thousand — Will Call Five Miles West of Atlantic on One Two Two Decimal One — Over.**

Station: **Negative Five Miles — Call Five Minutes West of Atlantic — Over.**

Aircraft: **Negative Five Miles — Call Five Minutes West of Atlantic — Over.**

Station: **That is Correct — Sydney Radio Out.**

You arrive five minutes west of Atlantic reporting point at 21.47 and have established contact with Sydney Radio:

Aircraft: **KTM Five Minutes West of Atlantic at Four Seven — Requesting Further Clearance — Over.**

Station: **ATC Clears GKTM to Descend Immediately — Report Leaving Nine Thousand Five Hundred — Traffic is Westbound Aero Commander Maintaining Eight Thousand Estimating Atlantic at Five Six (5) — Over.**

(5) Meaning there is an Aero Commander at 8000 ft. which will be over Atlantic at 21.56.

Aircraft: (Repeats clearance) **KTM is Cleared to descend immediately — Report Leaving Nine Thousand Five Hundred — Check the Traffic as Westbound Aero Commander at Eight Thousand Estimating Atlantic at Five Six — Over.**

Station: **Roger Sydney Radio.**

You report as you pass through the 9500-foot level on your descent and decide to check the weather at your destination:

Aircraft: **Leaving Nine Thousand Five Hundred at Five Zero — Requesting the Latest Torbay Weather and Altimeter.**

Station: **Check you leaving Nine Thousand Five Hundred at Five Zero — Here is the Latest Torbay Weather — One Thousand Scattered . . . etc. etc. — Altimeter Two Niner Zero Three — Over.**

Aircraft: **Weather Received — KTM Over.**

ARRIVAL

When approximately 15 miles from your destination, call the Tower. When the Tower replies, give your altitude, and position in miles and direction from the airport. The Tower will reply, giving you the runway to use, wind direction and velocity, traffic, and any other information or instructions considered necessary.

However, if the airport has ATIS and you have listened to and noted the information, inform the Tower on your initial contact that you have the ATIS information. Or, if you have listened to communications between the Tower and other airplanes and have noted the pertinent information about runway, wind, altimeter setting, etc., tell the controller that you have the "numbers".

Aircraft: **London Tower — This is Beechcraft Golf Sierra Tango Bravo — On One Two Two Decimal Five Megahertz — Over.**

Tower: **Beechcraft Golf Sierra Tango Bravo — This is London Tower — Go Ahead.**

Aircraft: **Beech STB — One Five Miles Northwest — At Three Thousand — Landing London — Over.**

Tower: **Beech STB — Cleared to Enter Traffic Circuit** (1) **— Runway Three Two** (2) **Wind Two Seven Zero Degrees at One Five — Altimeter Two Niner Seven Zero — Over.**

Aircraft: **Roger STB.**

(1) Should the traffic be right-handed instead of the conventional left-handed circuit, this will be indicated as follows: **Cleared to enter the Right Traffic Circuit.**

(2) Should the field have parallel runways, the appropriate runway will be designated as follows: **Runway Three Two Left.**

FINAL APPROACH

When you are on the base leg and about to turn in on final approach, request a **final approach clearance.** The Tower will give you any necessary instruction for final approach and, when the approach path and runway are clear, a **Landing Clearance:**

Aircraft: **Winnipeg Tower — This is Mooney Foxtrot Echo Lima Sierra — Gear Checked Down on Base Leg — Over** (1).

Tower: **Mooney Foxtrot Echo Lima Sierra — Cleared to Land.**

Aircraft: **Roger ELS.**

or

Tower: **Mooney Foxtrot Echo Lima Sierra — Widen your Approach — Cessna 310 Just Landing — You are Number Two.**

Aircraft: **Wilco ELS.**

Tower: (When runway is clear) **ELS — Cleared to Land.**

Aircraft: **Roger ELS.**

(1) Note: If the pilot does not report **"Gear Checked Down"** on final, the Tower may add **"Check Gear Down"** to the landing clearance. This is a precaution — not a confirmation that the gear is actually lowered.

STRAIGHT IN APPROACH

A pilot, after first reporting some distance from the field, may request a straight-in approach without entering the traffic pattern, if the traffic permits.

Aircraft: **Regina Tower — This is Beaver Foxtrot Hotel India Oscar — Approaching Runway Three Zero on a Heading Three Hundred Degrees Magnetic — Requesting a Straight In Approach — Over.**

Tower: **Foxtrot Hotel India Oscar — Cleared Straight In.**

Aircraft: **Roger HIO.**

TOUCH-AND-GO LANDINGS

Airplanes practising landings who wish to touch down and take off immediately, may be given a Touch-and-Go Clearance.

This should be requested by the pilot when turning off the base leg on to the final approach.

Aircraft: **Saint Stevens Tower — This is Bellanca Foxtrot November Whiskey Delta — Requesting a Touch-and-Go landing — Over.**

Tower: **November Whiskey Delta — Cleared Touch-and-Go.**

If it is not possible to approve the touch-and-go landing, due to other traffic, the tower will reply:

Tower: **November Whiskey Delta — Negative Touch-and-Go.**

TAXI CLEARANCE

After landing, taxi straight ahead and clear the runway as quickly as possible.

Your time of landing and taxi instructions will be given by the Tower as considered necessary, or if requested by the pilot.

Aircraft: **Foxtrot Yankee Union Delta — Taxi Instructions — Over.**

Tower: **Foxtrot Yankee Union Delta — On at One Five — Turn Right at end of the Runway and Taxi past the Tower to Gate Five.**

Aircraft: **Roger YUD.**

GROUND CONTROL

At certain designated airports, VHF Ground Control has been established to handle traffic on the ground and thus relieve traffic congestion on the Tower frequencies. Ground Control operates on specially designated frequencies—usually 121.9 MHz or, alternately, 121.7 MHz.

At airports where Ground Control is established, departing airplanes should communicate with the Tower on the appropriate Ground Control frequency for taxi and other clearance information, and remain tuned to this frequency until ready for take-off.

In-bound airplanes, after landing and clearing the runway or landing area in use, should tune in the appropriate Ground Control frequency for taxi instructions and further communication with the Tower.

Aircraft: **Richmond Ground Control — This is Aero Commander Golf Romeo Delta Tango — Taxi Instructions — Over.**

DISTRESS

The first transmission of a distress call should be made on the air-ground frequency that is in use at the time. If you are unable to establish communication on that frequency, the distress call and message should be repeated on the general distress frequency (121.5 MHz) or on any other frequency that is available, in the effort to establish as quickly as possible communication with another station. However, before changing frequencies, you should transmit a message indicating the frequency to which you intend to change.

The distress message should be repeated at intervals until an answer is received, allowing sufficient time between transmissions for a receiving station to reply.

The distress call format is the word MAYDAY repeated three times, followed by your aircraft identification three times. If time permits, your message should give your estimated position, altitude, the type of aircraft, the nature of the emergency, and your intended action (such as crash landing in timber, forced landing on water, etc.). Following the transmission of your message, hold the button on your microphone pressed down for 20 seconds—to enable D/F Bearings to be taken on you:

Aircraft: **Mayday — Mayday — Mayday — Foxtrot Oscar November Romeo — Foxtrot Oscar November Romeo — Foxtrot Oscar November Romeo — Five Zero Miles South of Grand Falls at One Seven Two Five Eastern — Four Thousand — Anson Five — Icing — Will Attempt Crash Landing on Ice —** (Keep microphone button depressed 20 seconds) **Foxtrot Oscar November Romeo — Over.**

Station: **Foxtrot Oscar November Romeo — Foxtrot Oscar November Romeo — Foxtrot Oscar November Romeo — This is Gander Radio — Gander Radio — Roger Mayday — Gander Radio Out.**

The distress signal has priority over all other transmissions and must be sent only on the authority of the person in command of the aircraft. It indicates that the aircraft sending the signal is threatened by grave and imminent danger and requires immediate assistance. Any person who knowingly transmits a fraudulent distress signal is guilty of an offense and liable to imprisonment or fine.

All stations hearing a distress call must cease any transmission of their own so as not to interfere with the MAYDAY message. Any aircraft that hears a distress call that has not been immediately acknowledged should make every effort to attract the attention of a station that is in a position to render assistance. In relaying a distress call, always follow it with **from** and the call letters of your aircraft.

If and when the aircraft is no longer in distress, a message must be made on the same frequency (or frequencies) as the MAYDAY message was sent, cancelling the state of distress.

Aircraft: **Mayday All Stations — All Stations — All Stations — This is Foxtrot Oscar November Romeo — Foxtrot Oscar November Romeo — Foxtrot Oscar November Romeo — At One Seven Four Zero Eastern — FONR Distress Traffic Ended — Ice Cleared — Returning Grand Falls — Out.**

URGENCY

Urgency signals are preceded by the word PAN repeated three times. They are given priority over all other communications except distress calls.

The urgency signal indicates that the station calling has an urgent message concerning the safety of a ship, or aircraft or of some person on board or within sight.

The urgency message should be addressed to a specific station and should be transmitted only on the authority of the pilot in command of the aircraft.

Aircraft: **Pan — Pan — Pan — Cleveland Tower — This is De Havilland Foxtrot Golf Foxtrot Echo — Advise Stinson Four Nine One November that his Undercarriage is Damaged — Over.**

Stations which hear the urgency signal should continue to listen for 3 minutes and then, if no further urgency message is heard, may continue normal operations.

Urgency messages may also be directed to all stations.

Station: **Pan — Pan — Pan — All Stations, All Stations, All Stations — This is Ottawa Radio Ottawa Radio Ottawa Radio — Emergency Descent at Ottawa Airport — Ottawa Tower Instructs All Aircraft Below Six Thousand Feet Within Range of One Zero Miles of Ottawa VOR Leave East and South Sectors Immediately — This is Ottawa Radio — Out.**

Urgency messages to all stations must be cancelled when the situation necessitating the message has been resolved or ended.

Urgency messages may also be used by aircraft experiencing difficulties that compel it to land but where immediate assistance is not required.

Aircraft: **Pan — Pan — Pan — This is Piper Golf Delta Bravo Kilo — Experiencing Partial Engine Failure — Will Land — Assistance Not Required.**

SAFETY

The safety signal is the word SECURITY repeated three times. The use of this signal indicates that a station is about to transmit a message concerning the safety of navigation, or important meteorological warnings to aircraft in flight.

The safety signal has priority over all other communications except distress and urgency.

Radio Navigation - - -

The use of radio in cross country flying has made navigation a relatively simple procedure. The VHF Omnidirectional Range Navigation System has made flight between VOR Stations as easy as following a highway. Distance Measuring Equipment relieves the pilot of the time consuming chores of plotting, measuring and computing to determine groundspeed and distance from destination information. The L/MF NDBs and Broadcast Stations are beacons on which a pilot can home or from which he can obtain a fix, if his airplane is equipped with Automatic Direction Finding equipment.

However, radio navigation aids should be considered a valuable aid — but not a substitute for — Dead Reckoning. Never neglect your compass. Keep an aeronautical chart handy and regularly check your position on it. Radios can, and do, fail and your insurance against becoming hopelessly lost is your conscientiousness in practising basic pilotage.

THE OMNIRANGE NAVIGATION SYSTEM (VOR)

The most widely used means of radio navigation is the Very High Frequency Omnidirectional Range (VOR). Strategically placed throughout Canada and the United States are hundreds of VOR ground stations that transmit signals that, with the proper airborne receiving equipment, can be used for navigation purposes.

The Omnirange System functions in the static free VHF frequency band between 108.00 and 117.95 MHz. Each station operates on its own assigned frequency.

The Omnirange Station puts out two signals. One of these signals is non-directional. It has a constant phase throughout its 360° of azimuth. It is transmitted at a rate of 30 times a second. It is called the **Reference Phase.**

The other signal rotates at a rate of 30 times per second. It is called the **Variable Phase.**

The Reference Signal is timed to transmit at the instant the Variable Signal passes Magnetic North. In all other directions, the Variable Signal will occur sometime later than the Reference Signal.

The principle of the Omnirange is based on this **Phase Difference** between the two transmitted signals (Fig. 1). By measuring the time it takes the rotating signal to sweep from North to where it reaches the receiving equipment in the airplane, it is possible to determine the bearing of the airplane from the station.

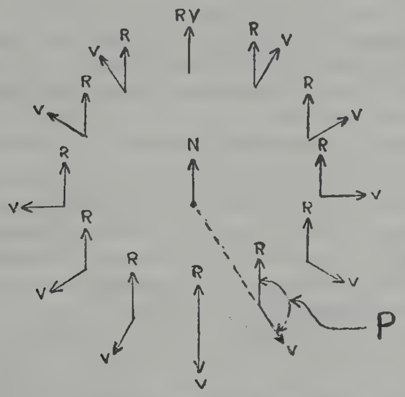


Fig. 1. Phase Angle (P) and Azimuth.

By the way of a simple illustration of this principle, let us use the case of an airport rotating beacon. The beam of light is rotating clockwise at, let us say, six rpm. This is one complete revolution every 10 seconds, or 36 deg. of azimuth per second. Suppose the green airport identification light was timed to flash each time the beam swept past Magnetic North.

Now if we had a stopwatch we could determine our direction from the beacon. When we saw the flash of the green light, we would start the watch. When the rotating beam swept past us, we would stop it. The number of seconds shown on the watch multiplied by 36 would be our magnetic bearing from the beacon.

Example: Time between flash of green light and sweep of rotating beam past us is four sec. 4 × 36 = 144. Then our bearing from the beacon is 144 deg. Magnetic. (Fig. 2.)

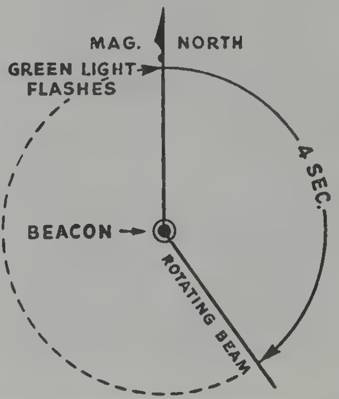


Fig. 2. Principle of the Omnirange.

This is exactly what the Omnirange equipment does for a pilot, except that the timing between the Reference and Variable Signals is done electronically, and the bearing obtained is any one of the infinite number of "beams" which radiate out like the spokes of a wheel from the Omnirange Station and which are referred to as **Radials.**

Radials are designated by numbers. Each radial is given a number which indicates its magnetic bearing **from** the station. For example: the radial "45" would be the radial you would follow if you wished to fly a magnetic track northeast away from the station. The radial is located 45° clockwise from the 0° radial which is always aligned with Magnetic North.

There are, of course, Omni bearings **towards** a station as well as away from it. If you were following the "45" radial **to** the station, you would be in a position southwest of the station. The "45" radial TO is a reciprocal of the 45 radial FROM.

Some authorities refer to Omni bearings as radials regardless of whether they are to or from the station. Others refer to Omni bearings as **Courses.** By definition, radial means "radiating outwards" and in order to avoid confusion, many pilots like to consider the radial as the magnetic bearing *away from the station,* and the course as the magnetic bearing *towards the station.* "45 FROM" would, therefore, be a radial away from the station, and "225 TO" would be a course towards the station.

A VOR Station is depicted on aeronautical charts by a station azimuth (or compass rose) superimposed over the site of the VOR transmitting station, which is represented by a six sided symbol. Fig. 3 illustrates the azimuth for the Vermilion VOR Station. The azimuth is marked off in increments of 5°. The 0° radial is aligned with Magnetic North.

The name of the VOR is given in the information box along with the three letter identifier and the associated morse code identification. The frequency of the station is given in Megahertz. The frequency for Vermilion is 114.5 MHz.

Several radials are drawn in (272°, 257°, 242° and 085°). These radials are used to provide a flight path between two VOR Stations. Such a specially designated flight path is called a Victor Airway. In Fig. 3, the 272° radial is Victor Airway 355 (V355).

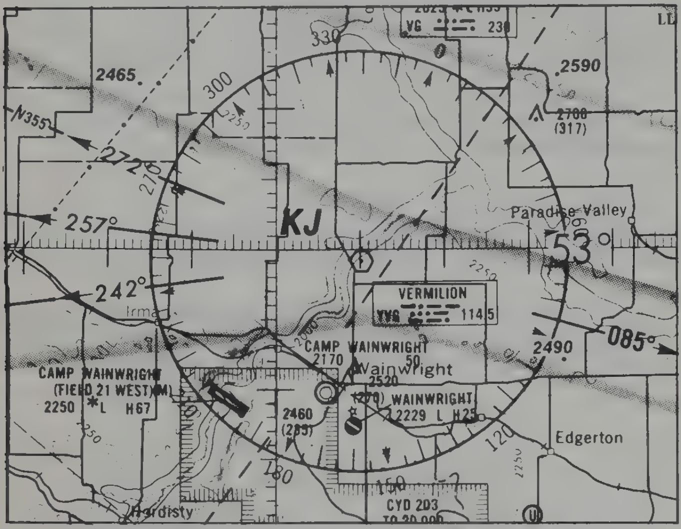


Fig. 3. How an Omnirange is shown on a map.

VICTOR AIRWAYS

Networks of VHF Airways which make use of Omnirange facilities criss-cross the whole of the United States and most of Canada. These Airways are referred to as **Victor (or VOR) Airways.** They are flown by reference to the Omni Stations, which are located approximately 100 miles apart along the airways. The Victor Airways are numbered like highways.

They are 9 nautical miles wide. They are depicted on aeronautical charts by shaded lines the outer edge of which denotes the outer limits of the airway.

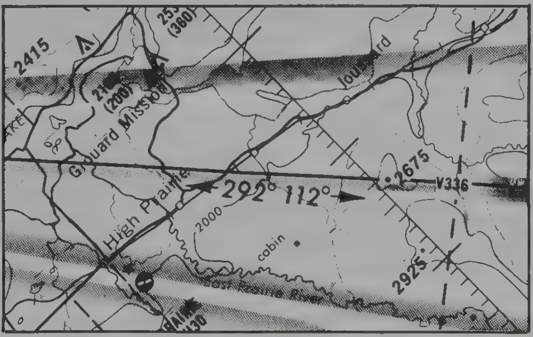


Fig. 4. Victor Airway (Controlled Airspace).

Note that the magnetic bearings of the airway illustrated are exact reciprocals: i.e. 292° and 112°. On some airways, these opposite bearings may not be exact reciprocals, due to differences in magnetic variation. For example, a certain Victor Airway may be 077° eastbound but be 261° westbound.

When flying Victor Airways, you fly the Omni radial which lies down the centre of the airway.

Under conditions of low visibility, it is extremely important to fly close to the centre line of the airway, particularly in the vicinity of terminal areas. An adjacent Victor Airway may lie as close as 15° to the one you are using—on which other traffic may be operating at the same altitude you are. Fig. 4 shows how a Victor Airway appears on an aeronautical chart.

ADVANTAGES OF VOR NAVIGATION

The Omnirange System provides a multiple number of courses towards and away from each station in the system. These courses are like invisible highways crisscrossing the continent on which the pilot can navigate to or away from any location.

The Omniranges may also be used to determine a fix. A pilot is able to establish his position by rapidly tuning two Omni Stations and reading off their bearings. These will give him two position lines. When the latter are drawn on a map, the point where they intersect will be his fix.

Because the Omni is **position** sensitive, rather than **heading** sensitive, a pilot can fly a straight line and not worry about compass corrections, variation or deviation. Wind drift is also compensated for automatically. As a result, the airplane can be accurately kept on course.

The Omni instruments in the airplane are designed to show the bearing or direction of the airplane from the Omni Station — *regardless of the direction the nose of the airplane may be pointing* (See Fig. 5). In other words, the Omni bearing is a **magnetic bearing** between the airplane itself and the Omni Station. When you fly towards or away from an Omni, *you do so by maintaining a line of constant bearing.* Obviously, to do this, you must keep kicking the nose around into wind to prevent the wind from drifting you off the bearing line you are endeavouring to maintain. In doing so, you are automatically correcting for wind drift with no effort or calculation of any kind on your part.

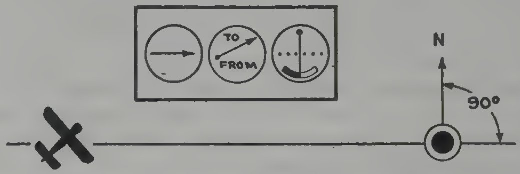


Fig. 5. Omnirange Bearing. The Bearing of the Station from the Airplane is 90°.

The accuracy of the course alignment of the Omnirange is within plus or minus 2 degrees. Very precise navigation is therefore possible.

The VOR frequencies are free of static and interference and therefore give reliable indications. Reception is dependent, however, on distance from the station and altitude. (See below)

DISADVANTAGES OF VOR NAVIGATION

The VOR signals, transmitted on VHF frequencies, are restricted to line of sight reception.

The curvature of the earth, therefore, has a pronounced effect on the distance at which a VOR signal can be received. At distances of about 45 s. miles from the station, the signal will be received at an altitude of 1000 feet. The farther from the station that the airplane is the higher it must be to receive the signal. (See Fig. 6. **Table of VHF Reception Distance** in Chapter **Radio.**)

At very high altitudes, it is possible to receive incorrect indications because of interference between two stations transmitting on the same frequency. Usually, the same frequency is assigned only to stations that are many hundreds of miles apart. However, on occasion, the areas may overlap and cause erroneous Omni readings.

The Omnirange signals are also affected by topographical features in the immediate vicinity of the Omni Station, such as fences, power lines, buildings, etc. This is called **Site Effect Error** and causes erroneous readings and sometimes complete blanking out of the signal.

In the close vicinity of mountains, the signals are sometimes reflected or completely masked out in the "shadow" of the mountain. This is known as **Terrain Effect Error.**

Errors are also occasioned by failure of parts of a particular receiver (**Receiver Error**) or by faults in the structure or equipment installed at a particular Omnirange Station (**Ground Station Error**).

The vagaries of the VOR system are not of great magnitude. Site and Terrain Errors are experienced for short periods and tend to average out before the airplane can respond. Receiver

Error can be eliminated by careful selection and proper maintenance of good reliable equipment. Ground Station Error, the most serious of those enumerated above, is seldom in excess of two degrees, and in no case greater than plus or minus 3-1/2 degrees of error in displacement.

These vagaries of the Omnirange appear in the form of minor irregularities such as course roughness, occasional brief flag alarm activity, course deflections, and limited distance range. Over unfamiliar routes, be on the alert for these abnormalities.

THE VOR STATION

Each VOR Station transmits on an assigned VHF frequency.

As well as the Omni signal, the station transmits a morse code three letter identification. For example: Toronto YYZ — • — —/— • — —/— — • •

Some Omni Stations are identified by a recorded voice identification, followed by three letters in code, e.g.: "Indianapolis VOR" (voice) • • / — • / — • • (IND in code). If the Omnirange Station is unattended and does not provide an air/ground communication facility, the word "Unattended" will be included. For example: "Cooksville Unattended VOR".

Always listen for the identification signal to be sure you have the right station.

All Canadian VOR Stations operate continuously. Most are equipped with an air/ground communications facility which allows pilots to contact Aeradio Stations. The pilot transmits on 122.2 MHz and receives on the VOR frequency. Scheduled weather broadcasts are transmitted over the VOR frequency at selected times, as is NOTAM information.

VOR Stations can also be contacted to request Direction Finding (DF) assistance. The VHF DF equipment that is in operation at most Aeradio Stations enables an Aeradio Station operator to advise a pilot of his bearing from the station. The VHF DF Service is discussed more fully in the Chapter **Radio.**

THE OMNI INSTRUMENTS

To use the Omninavigation facilities, the airplane must be equipped with a VHF receiver, a VOR Indicator and an antenna.

THE ANTENNA

The VOR signals are received by the antenna which is normally located on the top of the fuselage or at the tail cone area, where it is free of interference from other electrical equipment. The antenna is V shaped and made of flexible steel.

THE RECEIVER

The Omnirange receiver is usually incorporated in a unit that has both a transceiver for transmitting and receiving on the communication channels and a receiver for receiving the navigation channels.

The VHF NAV/COM unit illustrated in Fig. 6. is a typical modern piece of radio equipment. The COM side of the unit has already been discussed in the Chapter **Radio.**

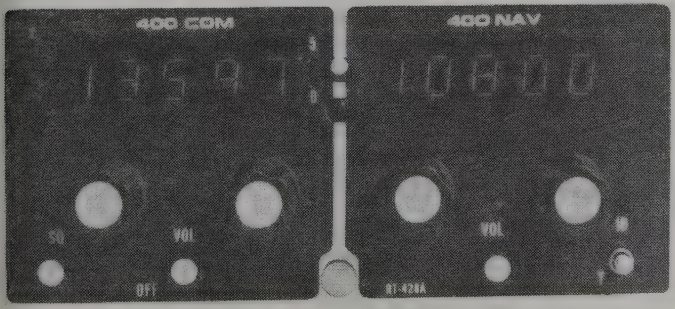


Fig. 6. VHF NAV/COM Radio Equipment.

The NAV side of the unit is capable of receiving 200 channels in the frequency range from 108.00 MHz to 117.95 MHz with 50 KHz spacing. The NAV receiver in Fig. 6 is tuned to 108.00 MHz.

The NAV receiver also functions as a receiver for the Glide Path and runway Localizer of the Instrument Landing System. ILS Localizers operate on odd tenth decimals (i.e. 108.10, 108.30, 108.50, etc.) in the VHF frequency range from 108.10 to 111.90 MHz. When the set is tuned to an ILS frequency, the corresponding Glide Path frequency (which transmits in the UHF band) is tuned in automatically.

THE VOR INDICATOR

The VOR Indicator combines three functions in one unit: A Bearing (or Course) Selector, a Course Deviation Indicator and a TO-FROM Indicator.

The VOR Indicator illustrated in Fig. 7. incorporates these three functions. It also incorporates the Cross Pointer that is necessary to give a visual indication of the airplane's position when the NAV receiver is tuned to an ILS Localizer.

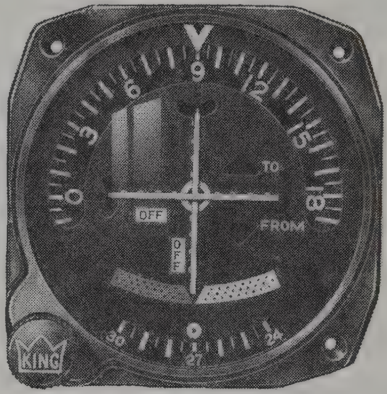


Fig. 7. Omni/ILS Indicator.

The **Omni Bearing (or Course) Selector (OBS)** has an azimuth dial graduated in 360 degrees and numbered every 30° from 0 to 33. The graduations and numbers appear in the semi circular upper window. The numbers represent Omni bearings (courses or radials). In the illustration, immediately below the Bearing Index (V), a bearing (course or radial) of 090° has been selected by the pilot. The numbers which appear in the smaller lower window are the reciprocal bearings or courses.

The **TO FROM Indicator** is located on the right side of the instrument above and below the horizontal bar. Since the magnetic bearing of an Omnirange radial can be ambiguous, the Sense Indicator is used to indicate whether the airplane is on a bearing **towards** or **away from** the Omnirange Station.

If the indicator shows TO, the bearing is towards the Station from the airplane. If the indicator shows FROM, the bearing is away from the Station towards the airplane.

The **Course Deviation Indicator (CDI)** is a vertical needle that moves to the right or left of the row of vertical dots to indicate whether the airplane is to the right or left of the course or radial which the pilot has set up on the Bearing Selector. The Course Deviation Indicator is often simply called the **Left Right Needle.**

When the NAV receiver is tuned to an ILS Localizer, the vertical needle indicates deviation from the selected Localizer course. The horizontal needle indicates deviation above or below the Glide Path. The ILS Landing System is more fully discussed later in this Chapter.

VOR TEST FACILITIES

VHF equipment should be tested periodically to determine its accuracy. Low power VHF Omnitest transmitters have been installed at various locations throughout Canada and the United States and provide a means of checking a VOR receiver while the airplane is on the ground. These transmitters radiate a signal such that an airplane will receive an indication as if it were positioned on the Magnetic North (000°) radial from the VOR facility. With the needle centered the Omni Bearing Selector should read 000° with the indicator in the FROM position or 180° with the indicator in the TO position. The bearing accuracy of the transmitted signal is maintained within a tolerance of 1°. An apparent error greater than 4° in the airplane VOR receiver is beyond acceptable tolerance.

Where there are no special Omnitest facilities, a pilot may test his equipment for accuracy by the following method. Tune in the frequency of the nearest Omni station and centre the needle. Then rotate the dial 180° and centre the needle again. The reciprocal of reading should be within 4 degrees of the original reading for permissable tolerance.

VOR NAVIGATION

To use the VOR Navigation System, you must first tune in the proper station on the VOR receiver. The frequency of a particular VOR Station is published in the information box for that station on the aeronautical chart. Always listen for the identification signal to be sure the proper station has been selected.

To select a radial, rotate the Bearing Selector. As you do so, the Course Deviation Indicator (CDI) will begin to move towards the vertical row of dots. When the needle becomes centred, the reading on the Bearing Selector is the **radial** transmitted by the Omni Station on which the airplane is located. Regardless of the heading of the airplane, it is somewhere on the radial indicated by the Bearing Selector.

The CDI needle, when centred, indicates that the airplane is located on the selected radial but it does not indicate on which side of the station the airplane is located. The TO FROM Indicator resolves this ambiguity.

THE TO FROM INDICATOR

Fig. 8 illustrates the sectors in which either a TO or a FROM signal is received when the Bearing Selector is indicating an Omnirange radial. For the illustration on the left, the 160° radial of a particular Omni Station has been selected on the Bearing Selector. In the illustration on the right, the 45° radial has been selected. If the airplane is anywhere within the unshaded segment, regardless of the direction the airplane may be heading, the TO FROM Indicator will read FROM the station. If the airplane is anywhere within the shaded portion, the TO FROM Indicator will read TO the station, even though the airplane may actually be heading in a direction away from the station.

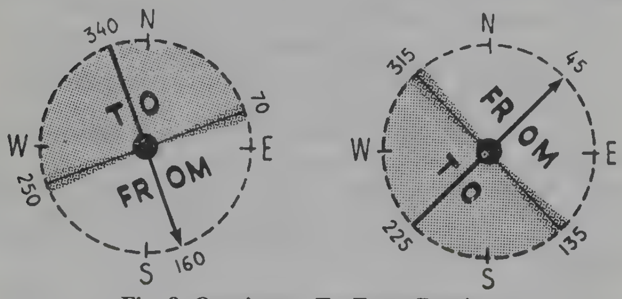


Fig. 8. Omnirange To-From Bearings.

If the airplane happens to be in a position exactly 90° to the selected radial, the opposing signals that actuate the TO and FROM Indicator cancel each other and produce an OFF situation.

In Fig. 9, the Bearing Selector in each airplane has been set to 0°. Airplanes A, B and H would show TO. Airplanes D, E and F would show FROM. Airplanes C and G would show OFF.

When the airplane passes over the Omni Station, the TO FROM Indicator will change from TO to FROM or vice versa to show station passage.

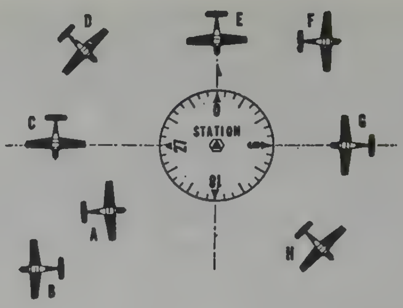


Fig. 9.

THE COURSE DEVIATION INDICATOR

The Course Deviation Indicator will remain centred as long as the airplane is actually on the course or radial indicated on the Bearing Selector. If the airplane is off course to the right of the radial, the CDI will swing to the left of centre. If the airplane is off course to the left of the radial, the CDI will swing to the right of centre. In other words, the CDI points in the direction in which the radial lies. To centre the needle, fly into the radial, that is, steer into the needle. When the needle centres, the airplane is back on course.

This is **normal needle sensing** and applies when the airplane is headed in the same direction as the radial selected. For example, if the selected radial is 90° and the airplane is headed in an easterly direction, normal needle sensing will apply.

If, however, the 90° radial has been selected, but the airplane is headed in a westerly direction, then **reverse needle sensing** will occur. To centre the needle, in this situation, it is necessary to fly away from the needle.

The easiest method of using the VOR System is to select a radial that is in the same general direction as the heading of the airplane and use normal needle sensing.

The CDI, as well as the TO FROM Indicator, gives an indication of station passage. As the airplane passes over the station, the needle swings to one side and then returns to its original position.

TO FLY A COURSE TOWARDS AN OMNIRANGE STATION

Suppose you wish to plan a flight from some place on the map to another place where an Omnirange is located. Measure the magnetic track on the map from the place where you are now to the Omnirange to which you wish to fly. (The magnetic compass rose printed around the Omni Station on the map is for your convenience in measuring.) The magnetic track you have just measured is the course you intend to make good to the station.

1. Set the Bearing Selector to the magnetic course you obtained above.
2. Head the airplane in a direction calculated to make good the intended course.
3. Observe the TO FROM Indicator. It should indicate TO.
4. The CDI will now point towards the direction the airplane must be steered to reach the selected course. Steer into the needle until the vertical needle is centred. Then alter course as necessary to keep the needle centred.

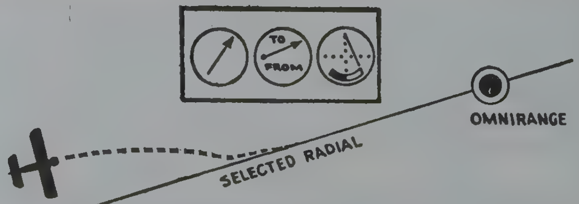


Fig. 10. Flying a Course towards an Omnirange.

When you pass over the station, the Sense Indicator will change from TO to FROM. This positively identifies your passage over the station. Suppose you should wish to return to the station. Execute a 180° turn — *and be sure to turn the Course Selector 180°*. If you do not do this you will be flying a course "towards" a station on a FROM indication. The sensing of the needle will be reversed, and instead of turning towards the needle, you will have to turn away from it to centre it.

So far we have laid much emphasis on the need of doing no more than simply "flying the needle". Now let us offer a word of caution. Flying the needle can be overdone! Always remember that your Omni equipment tells you *where you are rather than how to get there.* To get there, you must **head** the airplane in the right direction. Do not become "needle conscious" to the extent of neglecting your "heading consciousness". To navigate by Omni, always turn first to a heading approximately that of the course or radial you intend to make good—then use the needle as a **guide** to correct the heading, rather than as a primary flight instrument. By doing this, you will avoid swinging wildly back and forth across the intended course or radial, trying to get the needle to stay in the centre. Remember that the **Omni bearing** and **airplane heading** will never be very far out of agreement, the difference being the wind correction angle. So centre the needle by making gentle corrections to your **heading** rather than concentrating on the needle itself, and you will find that flying the Omni is the easiest thing you ever tried to do.

TO FLY A RADIAL AWAY FROM AN OMNIRANGE STATION

The procedure is exactly the same as that described above, except that the airplane is headed in a direction calculated to make good the radial **away from** the station, and the Sense Indicator will read FROM.

TO OBTAIN A FIX BY OMNIRANGE BEARINGS

In the same way that we were able to fix the position of an airplane by position lines obtained by compass bearings (See **"Position Lines"** in Chapter **Navigation)**, we can also obtain a fix by bearings taken on two or more Omni Stations.

The pilot of the airplane in Fig. 11 is flying along a Track, A-B. He wants to check his position. He tunes in the Omni Station Y, and rotates his Bearing, or Course Selector until the Course Deviation Indicator is centred. As will be seen, his Bearing Selector will read 273° (FROM). He now tunes in Omni Station X, and obtains a reading on his Bearing Selector of 185° (FROM). By drawing the two position lines, 273° and 185° from the Omni Stations on the map, the point where they intersect will be his position at the time the bearings were taken.

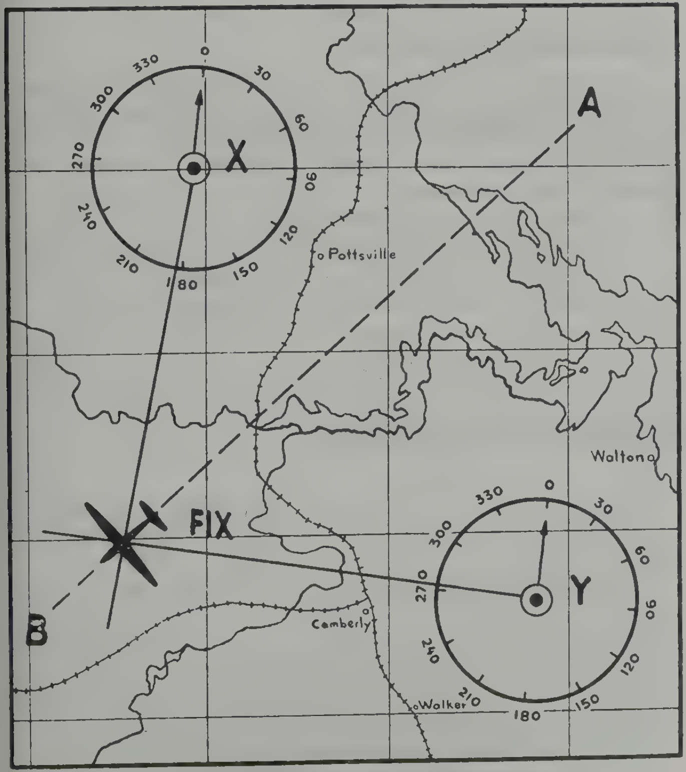


Fig. 11. Fix by Omnirange Bearings.

DUAL OMNI INSTALLATIONS

Many airplanes are equipped with two complete NAV/COM units. As well as providing the dependability factor that if one radio fails, the second is available for both navigation and communication purposes, the two NAV units allow the pilot to select and fly one radial to or from an Omni Station and at the same time, continuously take bearings on another off track station to determine his position (i.e. to obtain fixes).

TACAN (TACTICAL AIR NAVIGATION)

TACAN operates in the UHF 960-1215 MHz band.- Although it is primarily a military system, civil airplanes possessing the appropriate equipment, may use it as a navigational aid. It combines the functions of the civil VOR (Omnirange) and DME (Distance Measuring Equipment) and therefore indicates to the pilot the azimuth, or direction, of the station to which he is tuned, and also its distance in miles. Its use requires special TACAN equipment installed in the airplane.

VORTAC

In the past, TACAN was a separate navigation system providing azimuth and distance guidance to military airplanes. VOR/DME was a system designed to provide similar information to civil airplanes. It was found to be practical to combine them into a unified system by installing TACAN facilities at existing VOR stations, and thus bringing all air traffic, both military and civil, under one common control using coincidental facilities operating from the same geographical locations. The collocated facilities are called VORTACs.

VORTAC, therefore, gives the pilot the azimuth, or direction, to or from the station to which he is tuned on VHF and both the direction and distance on UHF.

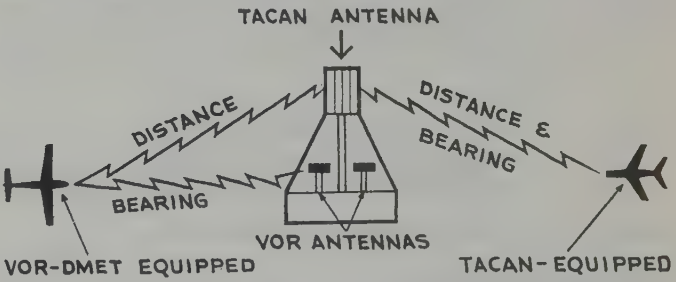


Fig. 12. VORTAC Station, showing facilities available for use with various types of airborne equipment.

A pilot with an Omnirange receiver can tune in a VORTAC station for directional guidance.

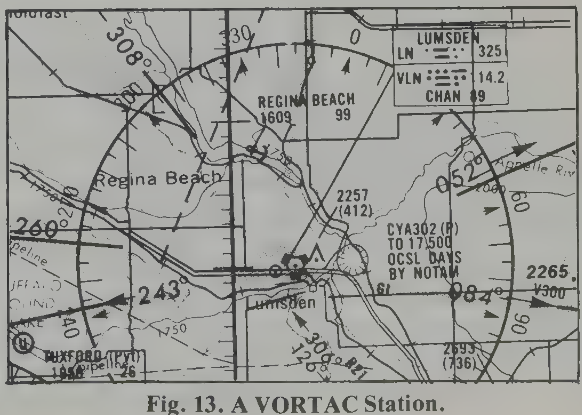


Fig. 13. A VORTAC Station.

A pilot with DME equipment can interrogate the VORTAC station for distance information. (DME is discussed more fully later in this Chapter.)

A pilot with TACAN airborne equipment can get both azimuth, and distance from the VORTAC facility.

VORTAC stations are depicted on aeronautical charts in the same manner as are VOR stations, except that the symbol sited at the location of the VORTAC transmitter is a three sided figure as shown in Fig. 13. The TACAN channel, as well as the VHF frequency, is printed in the information box.

RADIO BEACONS

As additional aids to navigation, several types of Radio Beacons are in use along the airways.

NON-DIRECTIONAL BEACONS

Low powered Non-Directional Beacons operate mostly in the 200-450 KHz band. They are installed at certain locations near airports to assist with instrument approach and Holding Pattern procedures.

Non-Directional Beacons may be installed at the Outer or Middle Marker positions of the ILS. They operate, however, independent of the ILS on a continuous basis. They are identified by a single letter. e.g.: Ottawa—"O". These NDBs usually have a range of less than 25 nautical miles.

NDBs of higher power are also in use as enroute facilities replacing the old L/MF Radio Ranges which have now mostly all been converted to Non-Directional Beacons. They transmit a two-letter identification. e.g. Flin Flon—"FO". ADF equipment is required in the aircraft to use these navigational facilities.

NDBs are shown on aeronautical charts by shaded circles. Fig. 14 shows the NDB at Barchane, near Edmonton. The name of the NDB, its two letter identification in letters and in morse code and the LF frequency on which it transmits are all given in the information box adjacent to the facility on the map.

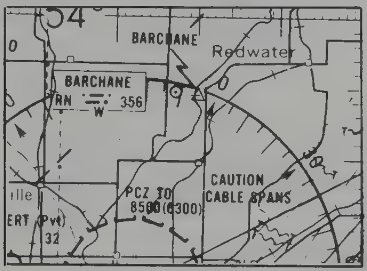


Fig. 14. Non Directional Beacon.

Z TYPE MARKER

The Z Type Markers operate on 75 Megahertz and require a VHF receiver in the airplane for their reception. They transmit a cone-shaped signal field over the station and provide a means of positively identifying passage over the transmitting station. They are identified by a sound signal and by the activation of a light signal on a special receiver in the airplane.

Beacons of this type are used for Marker Beacon installations in the Instrument Landing System.

FAN TYPE MARKER

A Fan Type Marker also operates on 75 Megahertz.

Fan markers are elliptical in shape and broadcast a signal roughly 3 miles wide and 12 miles long that can be received aurally or by blinking lights only when directly overhead.

Low powered Fan Markers are used in the Instrument Landing System as Outer and Middle Markers.

BONE SHAPED MARKER

Bone, or dumb-bell shaped Markers serve much the same purpose as Fan Markers. Because of their narrow width at the centre (approximately 1-1/2 miles) they provide a more definite Holding Pattern and are provided primarily for approach control.

MARINE BEACON

Marine Beacons transmit in the Medium Frequency band a signal consisting of several letters in code. They do not transmit continuously, except when there is fog, but at periods of so many minutes past the hour which are clearly stated on aeronautical charts.

COMPASS LOCATORS

Compass Locators are low-powered non-directional radio beacons operating mostly in the 200-450 KHz band. They are frequently installed in the same locations as the Outer and Middle Markers of the ILS. When an airplane is equipped with dual ADF, they can be used

1. To home to the Outer Marker,
2. To assist the pilot in executing a Holding Pattern.
3. To assist in tracking the approach course.
4. To indicate when the Markers have been passed.

INSTRUMENT LANDING SYSTEM

The Instrument Landing System, or ILS, is a method of guiding a pilot through the overcast to a landing by means of visual reference to instruments in the cockpit.

The system consists of a Localizer, a Glide Path and two VHF Marker Beacons transmitting on 75 MHz.

The **Localizer** is a radio beam resembling a half-moon shaped disk standing on its edge. Its vertical plane is aligned with the runway and its purpose is to keep the pilot lined up with the runway during his descent. The Localizer transmits on one of twenty frequencies in the VHF band between 108.1 and 111.9 MHz (on odd frequencies). Each Localizer produces two courses, a Front Course and a Back Course. The course normally used with the Glide Path is the Front Course. The reciprocal course is the Back Course.

The **Glide Path** is a radio beam shaped like a platter lying on its side. This beam guides the pilot along the proper downward approach path to enable him to touch down on the threshold of the runway. The Glide Path operates on one of twenty frequencies in the UHF band between 329.2 and 335.0 MHz. Each UHF Glide Path frequency is "paired" with a corresponding VHF Localizer frequency. The Glide Path projection is normally set at an angle of 3°.

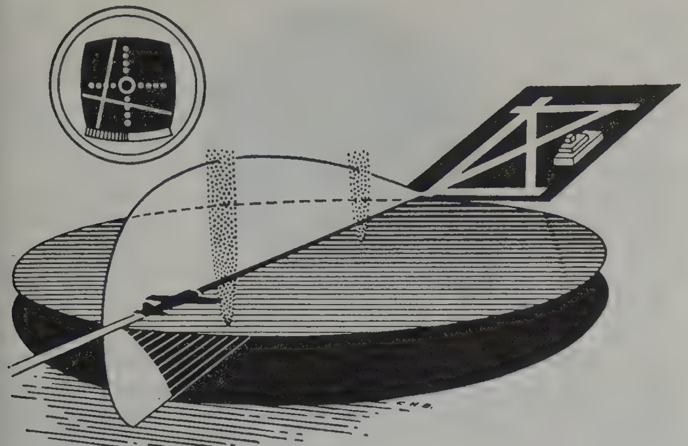


Fig. 15. The Instrument Landing System.

The insert shows the Localizer and Cross-Pointer Indicators. The instrument illustrated shows the pilot is off the Localizer beam to the right, and must steer left "into the needle" to centre the vertical needle and get back on the beam. He is above the Glide Path, and must fly down "into the needle" to centre the horizontal needle and get back on the Glide Path.

Note: The above needle indications apply when the pilot is inbound towards the field. When flying outbound away from the field, the needle sensing is reversed.

The instrument in the cockpit which enables the pilot to follow these two beams is the Course Deviation Indicator and Cross-Pointer Indicator of the VOR Indicator (See Fig. 7 and the insert in Fig. 15). The vertical (Localizer) and the cross (Glide Path) pointers give the pilot his directions. If he gets off to the right or left of the approach to the runway, the vertical needle tells him which side and how far. The horizontal needle tells him when he is above or below the proper glide path.

In Fig. 7, the windows adjacent to the Glide Path and Localizer needles (which read "OFF") are where the flag alarm signal appears when a weak, unreliable or null signal is being received.

The segments below the Cross-Pointer Indicator are the blue and yellow sectors of the Localizer course. The blue sector is 150-cycle and is always on the right of the inbound course. The yellow sector is 90-cycle and is always on the left. The signals overlap down the centre line of the runway and this line extended is the **Front Course** of the Localizer.

The **Marker Beacons** project a fan shaped or cone shaped vertical projection of narrow dimensions upward on a frequency of 75 MHz. There are two of these Marker Beacons on the Front Course. Sometimes one is installed on the Back Course. Their purpose is to let the pilot know his distance from the threshold of the runway when he is making an instrument landing approach. The **Outer Marker** is about 4 n. miles from the threshold. The **Middle Marker** is about 3500 feet from the threshold. The Outer Marker causes a light on the Marker Beacon Receiver to flash a series of dashes, the Middle Marker a series of dots and dashes. In addition to these visual indications, the pilot may also receive the signals aurally in his earphones. The **Back Marker** is located about 3 to 5 n. miles from the threshold of the runway on the Back Course and keys a series of dots on the Marker Beacon Receiver.

Fig. 16. Narco Marker Beacon Receiver.

FM/Z means Fan Marker or Z Marker — Indicated by steady white light . . . OM means Outer Marker — identified by flashing blue light . . . MM means Middle Marker — identified by flashing amber light.

The Marker Beacons tell the pilot his distance from the runway as he intercepts the Marker signals.

A further development of the system combines ILS with the automatic pilot, enabling the airplane to be flown down the two beams to a landing automatically.

The ILS Localizer at most installations provides a valid signal coverage through 360°. At some airports, however, the ILS Localizer is suitable for only Category II operations; the coverage of the ILS is valid and reliable through 45° on either side of Front or Back Course nominal approach path. Beyond 45° of the centre line, false or erratic ILS indications may be received.

ILS frequencies are identified by the two letter identifier of the installation preceded by the letter "I"; a 1.2 second space separates the "I" from the standard identifier. For example, "I OW" — ILS Ottawa.

THE AUTOMATIC DIRECTION FINDER (ADF)

The Automatic Direction Finder is a very useful aid to aerial navigation. It can be used for homing to or finding direction from any station that broadcasts in the Low and Medium Frequency radio bands.

Aviation installations that operate in the Low Frequency band include Non-Directional Beacons, ILS Compass Locators and the Low Frequency Radio Range Stations. (There are very few of the latter left in existence. Almost all of the old Radio Ranges have been converted to NDBs.) The ADF is also able to receive commercial AM Broadcasting Stations and home on them.

ADF EQUIPMENT

The ADF system consists of an ADF Receiver, a Loop Antenna, a Sense Antenna and a Bearing Indicator.

ANTENNAE

Two antennae are required for ADF operation. One of these, known as the **Sense Antenna,** is a non-directional antenna that has the capability of providing directional information.

The other antenna is a **Loop Antenna** which senses magnetic bearing from the airplane to the station.

Back in the early days when ADF equipment was first introduced, the loop antenna was a complicated installation that had to be manually rotated to pick up maximum and minimum signals from a station. Modern ADF equipment is manufactured on the principle of solid state circuitry and has fewer moving parts and is therefore easier to operate and is considered more reliable.

The sense antenna usually is a long wire installed on the top of the airplane, stretching from an insulator near the top of the fuselage back to the stabilizer.

The loop antenna, a metal ring enclosing coils of insulated wires, is usually contained within a streamlined housing mounted well forward on the underside of the fuselage.

Very recent innovations in ADF equipment incorporate both antennas in a single blade antenna installed on the top of the fuselage that includes both the sense and the loop antenna in one unit.

THE ADF RECEIVER

Modern ADF receivers are digital tuned providing rapid and precise tuning to any desired frequency. They receive stations throughout the Low and Medium Frequency band.

The ADF receiver, like the Bendix ADF pictured in Fig. 17, receives information from the antenna and translates it into movement of the needle of the Bearing Indicator.

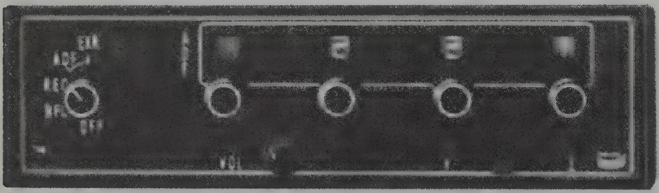


Fig. 17. Bendix Automatic Direction Finder.

The ADF receiver incorporates a five position function selector switch.

The REC position (on other models of ADF equipment, this position is sometimes called ANT for antenna) selects only the non-directional or sense antenna. The loop antenna and therefore the Bearing Selector are disconnected from the system. With the switch in this position, the receiver operates as an ordinary L/MF receiver, receiving the voice facilities of the station to which it is tuned. This switch position is used for station identification or for listening only.

When operated in the ADF position, the receiver selects the automatic direction finding loop antenna which in combination with the signal received by the sense antenna gives the homing capability of the ADF. The audio feature of the REC position is retained but usually a pilot turns down the volume once he has positively identified the station.

The EXR position is a feature of the Bendix ADF. It provides extended range selection, permitting strong reception of stations at great distance.

The BFO (Beat Frequency Oscillator) selection provides an aural aid to tuning. It should be used only in tuning unmodulated signals, such as the CW (continuous wave) signals of the long range Consolan Navigation System. It is not designed to be used with the modulated signal that is transmitted by NDBs or Commercial Broadcast Stations whose signals it can distort. When using the BFO function, signal reception is determined by the strength of the audio tone of the BFO. After the station is tuned and identified, the function selector switch should be repositioned at ADF.

THE BEARING INDICATOR

An ADF Bearing Indicator incorporates a bearing pointer and an azimuth dial which is graduated in degrees from 0 to 360. Some Indicators have a fixed card, such as that in Fig. 18. Others have a movable card, such as that in Fig. 19.

With a Bearing Indicator with a fixed card, the nose of the airplane is always oriented to 0° on the Bearing Indicator, regardless of the actual magnetic heading of the airplane.

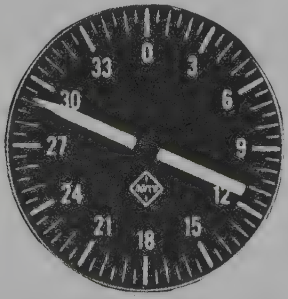


Fig. 18. ADF Bearing Indicator (Fixed Card).

With a Bearing Indicator with a movable card, the pilot is able to rotate the azimuth card so that it corresponds with the DG heading of the airplane.

Regardless of which type of Bearing Indicator is used, the bearing pointer always points in the direction of the station to which the receiver is tuned.

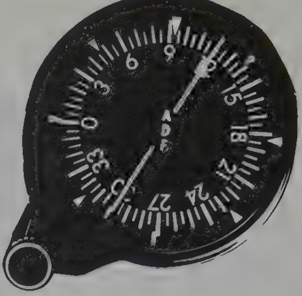


Fig. 19. ADF Bearing Indicator (Movable Card).

The loop antenna which senses the magnetic bearing of the station is positioned in relation to the longitudinal axis of the airplane. It measures, and the ADF pointer on the Bearing Indicator displays, the number of degrees, measured clockwise, between the longitudinal axis of the airplane and the station. This is known as a **Relative Bearing.**

The Magnetic Bearing of a station can, therefore, be determined from the displayed information. It is the sum of the Magnetic Heading of the airplane and the Relative Bearing.

For example, the airplane in which the ADF in Fig. 18 is installed is flying on a magnetic heading of 090°. The ADF Bearing Indicator (fixed card) indicates that the station to which the ADF receiver is tuned has a Relative Bearing from the airplane of 290°. The Magnetic Bearing to the station (i.e. the magnetic heading to which the airplane would have to turn in order to fly directly to the station) would therefore be 020° (090° + 290°).

An ADF Bearing Indicator with a movable azimuth card automatically displays the Magnetic Bearing of the station. In Fig. 19, the azimuth card of the Bearing Indicator has been rotated to 090° to correspond to the DG heading of the airplane. The pointer indicates that the station to which the ADF in this case is tuned has a Magnetic Bearing of 120° (the Relative Bearing is 30°).

ADF NAVIGATION

First of all, let us review the behaviour of the Bearing Indicator in various flight situations.

Let's take an example of an airplane with a Bearing Indicator with a fixed card. If the airplane is heading directly towards the station, the Bearing Indicator pointer will point straight up to 0° (towards the nose of the airplane). If the airplane is heading directly away from the station, the pointer will point straight down to 180° (towards the tail of the airplane). If the airplane turns 90° to the signal from the station, so that the station is on its left, the pointer will point to 270° (towards the left wing). If the station is on the right, the pointer will point to 90° (towards the right wing).

Suppose that the Bearing Indicator has a movable card. The airplane in the above example is on a heading of 20° Magnetic. The pilot has rotated the azimuth card of the Bearing Indicator to set 20 under the upper azimuth index. If the airplane is flying directly towards the station, the pointer will point straight up to 20°. If the airplane is heading directly away from the station, the pointer will point straight down to 200° (20° + 180°). If the station is directly off the left wing, the pointer will point to 290° (20° + 270°). If the station is off the right wing, the pointer will point to 110° (20° + 90°).

Now, let us suppose that an airplane is flying a track that will take it directly over the station to which the ADF is tuned. On the heading in to the station, the ADF pointer will point to 0° (fixed card). As soon as the airplane passes over the station, the pointer will swing around and point to 180° as the airplane heads away from the station.

Let us suppose that an airplane is flying a track that will take it past a station that is off its right wing. As the airplane approaches and passes the station, the ADF pointer will gradually increase its reading from its initial indication, past 90° and on towards 180°. As long as the airplane maintains a constant heading, the bearing pointer, of course, will never point directly to 180° since the station will never be directly behind the airplane.

In the following discussion of how to use the ADF, we will assume that the airplane is equipped with an ADF Bearing Indicator with a fixed card.

HOMING TO A STATION

In order to fly directly to the ADF facility to which the receiver is tuned, simply turn the nose of the airplane until the pointer of the Bearing Indicator points to 0°. Keeping the pointer on zero will result in a straight course to the station. On passage over the station, the pointer will swing around to 180° indicating that the station is now behind. The airplane is then able to track away from the station by keeping the pointer of the Bearing Indicator on 180°.

The above procedure is valid in a no-wind situation. The wind, however, tends to drift the airplane to one side or the other of a straight line to the station. A continuous process of correction of drift occurs as the ADF keeps heading the nose of the airplane towards the station. The resultant track flown is a curved line (Fig. 20).

The progressive change in the heading of the airplane will be indicated to the pilot by the magnetic compass or Directional Gyro.

In a cross wind situation where the wind is causing the airplane to drift away from the straight line track to the station, it is possible to narrow the curvature of the track by the following method:

The pilot has tuned the station on which he wishes to home and has centred the ADF pointer to 0°. As the track that he intends to fly is 090° Magnetic, the Directional Gyro will read 090° (Fig. 20. A)).

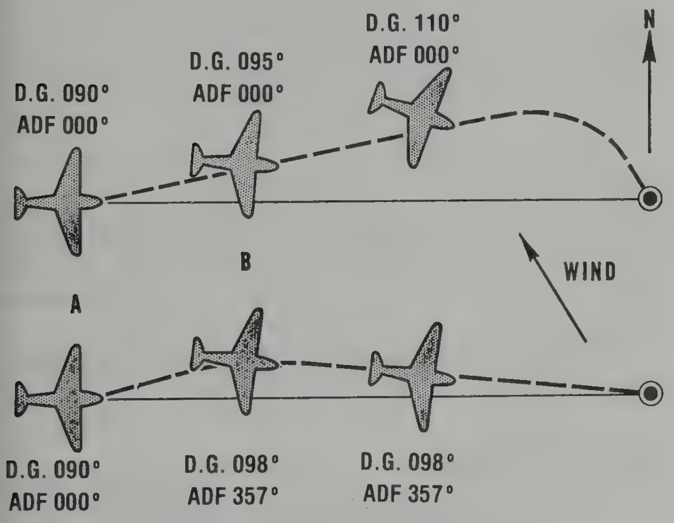


Fig. 20. Correction for Wind Drift.

After flying some minutes, the pilot notes his heading by D.G. has altered to 095°. He, therefore, realizes that he is drifting to port and that the wind is from the starboard. He heads the nose of the airplane, say, 3° more into the wind, steering 357° by ADF instead of 0° (098° by D.G.). (Fig. 20. B)

Note that when the heading is altered to starboard by the Directional Gyro (i.e. increases), the heading on the ADF alters to port (i.e. decreases).

If his heading continues to alter to starboard by D.G., he should steer a few more degrees into wind and continue this process until he finally observes that his heading by D.G. remains constant. He has now counteracted wind drift and established a straight heading towards the station.

TO INTERCEPT AN ADF TRACK

Sometimes a pilot may wish to fly a specific track into a station. This would happen when an ADF facility, such as an NDB, is located several miles from an airport. The extension of the magnetic track joining the NDB to the airport will be the track the pilot needs to intercept and turn to in order to arrive over the station on the proper heading to reach the airport.

After tuning in the station, the pilot should select a magnetic heading by D.G. that will intercept the required track to the ADF facility. By applying the formula given above (i.e Magnetic Heading plus Relative Bearing equals Magnetic Bearing to the Station), he can determine the Relative Bearing shown on the ADF Indicator that will inform him when he intercepts the required track.

For example, the track to the NDB that the pilot wishes to intercept has a Magnetic Bearing of 120°. The Magnetic Heading selected by the pilot in order to make the interception is 050°. The ADF Indicator should indicate a Relative Bearing of the station of 070° when the airplane intercepts the track (Magnetic Bearing of 120° minus Magnetic Heading of 050° equals Relative Bearing of 070°).

On intercepting the track, the pilot should turn the nose of the airplane until the Bearing Indicator pointer centres on 0° and then keep the pointer on 0° to arrive over the station.

In actual practice, some allowance should be made for the turn. The turn onto the desired track should be started, therefore, a few degrees before the ADF pointer reaches the required Relative Bearing.

TAKING BEARINGS

Bearings can be taken on ADF facilities in the same way as they can be taken on VOR Stations.

To take a bearing on an NDB or a Broadcasting Station, etc., that is off track, tune in to the frequency of the station. The pointer on the Bearing Indicator will indicate the direction of the station from the heading, or longitudinal axis, of the airplane. This is, as we have already learned, a Relative Bearing from the airplane to the station.

The Magnetic Bearing of the Station is the sum of the Magnetic Heading of the airplane and the Relative Bearing.

To plot a position line on an aeronautical chart, the Magnetic Bearing of the station must be converted to a True Bearing by applying deviation and variation.

Fig. 21 graphically shows how to convert a Relative Bearing to a True, or Geographical, Bearing.

The Relative Bearing of the station from the airplane is 30 degrees.

The Compass Heading of the airplane is 75°. Therefore, the Compass Bearing of the station is 105°.

By applying the deviation of 5°W and the variation of 10°W, the True Bearing of 90° is determined.

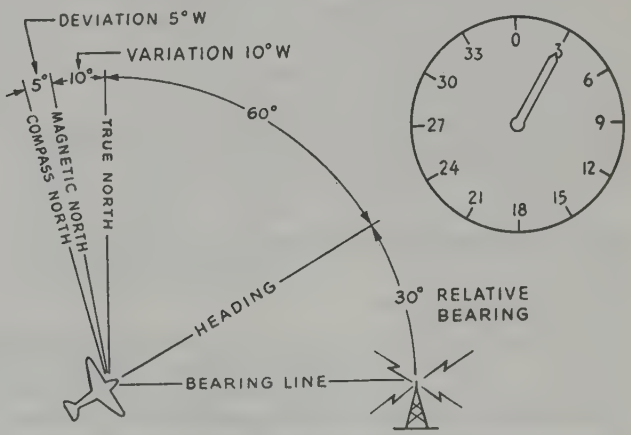


Fig. 21. Conversion of a Relative Bearing (shown on dial) to a Geographical Bearing.

The True Bearing can be plotted as a position line on an aeronautical chart. Draw a line on the map **away** from the station, that is, using the reciprocal of the Bearing. This is a position line, somewhere on which the airplane is known to have been at the time the bearing was taken.

When two or more bearings are taken nearly simultaneously on several different stations, and the position lines plotted on a map, the point where the position lines intersect will be a **fix** (the position of the airplane at the time the bearings were taken).

When plotting a fix by two or more position lines, the angle between the position lines should not be less than 30°.

DUAL ADF

Some airplanes are equipped with two Automatic Direction Finders. With dual ADF, a pilot may take simultaneous bearings on two stations, or he may home on one station and at the same time obtain a continuous bearing on another station, giving him a running position fix.

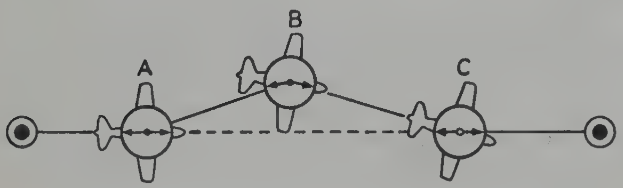


Fig. 22. Correction for Wind Drift for Dual ADF.

A. Pilot tunes one ADF to station ahead and the other to station behind. Dual pointers are on reciprocal bearings. B. Wind drifts pilot to left of track. Dual pointers no longer on reciprocal bearings. C. Pilot steers right until dual pointers are on reciprocal bearings again, indicating he has regained his track. For remainder of flight pilot maintains heading which will keep dual pointers on reciprocal bearings.

Dual ADF may be used to correct wind drift when homing. This is done by tuning one receiver to a station ahead and the other to a station behind. The heading is adjusted to keep the two needles in line, that is, on reciprocal bearings. (Fig.22.)

At stations where Compass Locators are installed, dual ADF is particularly useful to a pilot on instruments executing a Holding Pattern procedure, and can also be used to track the approach course to the runway.

OSCILLATION OF THE NEEDLE

Normally, a small degree of needle oscillation is a built-in feature of the Automatic Direction Finder. It indicates to the pilot that the instrument is functioning. Wide fluctuations of the needle, however, may be due to the following causes:

1. Bad static conditions.
2. A weak signal. (Station tuned too far distant or not sufficiently powerful.)
3. Airplane is midway between two stations which are both transmitting on the frequency tuned.

When wide oscillation, or "hunting" of the needle occurs, average the oscillation and fly the average heading.

INACCURACIES OF THE ADF SYSTEM

QUADRANTAL ERROR

The ADF is affected by an error very similar to deviation in the magnetic compass. This is called **Quadrantal Error.** It is caused by refraction, or bending of the incoming radio waves by the metal structure of the airplane. Quandrantal Error is minimal at the cardinal points (off the nose, tail and wing tips) of the airplane and maximum at bearings in between. Most ADF receivers have provisions for making a partial correction for this error. In this case the loop antenna should be installed in a position on the airplane where the built-in Quadrantal Error compensation matches the error caused by the airplane. But this is difficult and time consuming and rarely done. The Quadrantal Error can be determined by "swinging" the airplane both on the ground and in the air. However, this too is difficult to do and therefore is rarely done. Usually the error is less than 10° and since the system is accurate off the nose and other cardinal points, the Quadrantal Error does not affect operation of the ADF significantly.

NIGHT EFFECT

The Low and Medium Frequency radio bands produce both ground and sky waves, as has been pointed out earlier. The ADF homes on the ground waves. At night, however, the sky waves are much stronger than in the day time since at night they are most reflected by the Ionosphere. Since the sky waves may be arriving from any direction depending on how and where they have been reflected, they cause errors in the ADF bearing indication. The Bearing Indicator will swing rapidly as the sky wave changes. This is called **Night Effect.** The farther from the station, the more pronounced will be the Night Effect. Within some minimum distance of the station (varying from 20 to 50 miles), the Night Effect usually disappears. Night Effect is also more pronounced at the higher frequencies so that homing on a Broadcast Station will be more affected than on an NDB beacon. In order to minimize Night Effect, therefore, choose a station to home on, if possible, with a low frequency.

TERRAIN EFFECT

Coastal Effect

As radio waves pass from land to water, their direction of travel is changed. This is known as Shoreline Effect. Because of this, a bearing taken on an inland station from an airplane over water is inaccurate if it makes an angle of less than 30° with the shoreline. At greater angles, bending is negligible. When taking bearings over water, therefore, choose either stations right on the shore, such as marine stations, or stations so located that bearings on them make angles greater than 30° with the shoreline.

Mountain Effect

In mountain terrain, the signal is reflected off the side of mountains. The signal that arrives, therefore, at the ADF loop antenna may not be coming directly from the station. Erroneous and fluctuating bearings may be registered on the ADF indicator.

Ore Deposits

Ore deposits will sometimes cause the needle of the ADF to deflect off course.

ICE AND SLEET

Accumulation of ice and sleet on the antennae tends to produce erroneous readings of the ADF needle and also reduce signal strength.

PRECIPITATION STATIC

When flying in heavy rain or snow, static may be encountered on the Low and Medium Frequency bands. This static may be severe enough to interfere with the pointing capabilities of the Bearing Indicator needle. Reception of the audio signal may be so poor that identification of the station is impossible.

Precipitation static can be lessened by reducing the airspeed of the airplane.

Thunderstorms, containing large charges of static electricity, also interfere with the L/MF radio waves and cause erroneous readings of the ADF.

DISTANCE MEASURING EQUIPMENT (DME)

The purpose of the DME is to give the pilot a continuous reading of his distance to a fixed ground station. This ground installation is usually a VORTAC or a TACAN station transmitting a radar beacon on UHF.

The airborne equipment transmits pulses to the ground station that, in effect, ask ''How far am I from your station?''. Each aircraft ''interrogation'' has a unique transmission rate or pattern which the ground station reproduces in its replies to an individual aircraft even though transmitting on the same frequency to all aircraft working the station. The airborne DME receiver selects the reply pulses designated for itself (i.e. those with the same rate relationship as used in its own original transmission), measures electronically the time interval between its own transmission and the received reply, converts the elapsed time into a mileage figure which is continuously displayed in the cockpit indicator as the **slant range** from the airplane to the station. The range increases as the plane flies away from a station and decreases as it approaches the station.

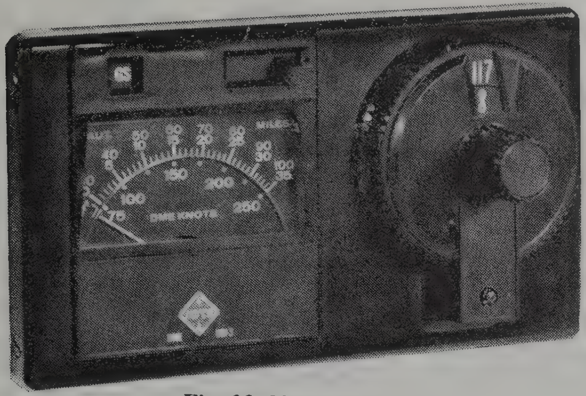


Fig. 23. Narco DME.

Slant range can be converted into ground distance by the following formula: ground distance is the square root of S^2 (slant range in nautical miles) minus A^2 (altitude in nautical miles). When the slant range is more than double the altitude, the difference between slant range and ground distance is negligible. However, when the aircraft is in the vicinity of a station and at high altitude, the difference between slant range and ground distance will be appreciable. In such a case, the pilot must employ the above formula to determine his actual ground distance from the station unless his DME includes a component solver that converts slant mileage to horizontal mileage automatically.

In practical application, the DME readings can be considered accurate if the airplane is over 5 miles from the station. Within 5 miles, slant range must be considered. Directly over a VORTAC installation, the DME will read altitude above the station.

Most DME units also have the capability to give a groundspeed reading.

The DME pictured in Fig. 23 is a typical airborne unit. The VORTAC frequency is selected by the selector knob on the right. A three position selector switch permits the pilot to read distance to or from the station in the 0 to 30 mile range or in the 30 to 100 mile range. The third position gives a groundspeed reading.

All DME distance readings are in nautical miles and the groundspeed readings are in knots.

A DME groundspeed reading, however, is accurately displayed only when the airplane is flying on a course inbound or outbound from a VORTAC station. When the airplane is flying past a station, the DME groundspeed reading will be meaningless because of the principle on which the DME makes its computations. An inaccurate reading will also be displayed when the airplane is passing directly over the station. The groundspeed indicator will drop to ''O'' for the period that the airplane is over the VORTAC installation.

The groundspeed feature of the DME is of especial value to the pilot for it allows him to choose the altitude where he will encounter the most favourable winds. By flying at several different altitudes and observing the groundspeed readout on the DME, he can determine at which altitude the groundspeed was highest thereby indicating the most favourable winds.

The DME is also used in making orbitting or arc approaches to an airport. The **DME Arc** is a course flown at a constant DME distance around a navaid such as a VORTAC which provides distance information. In a case where the VORTAC is located a few miles (for example, 5 miles) from the airport, the pilot, by keeping that mileage reading constant on his indicator (5 miles in our example), will be able to bring his airplane right over the airport. The exact position of the airport can be pinpointed by using the Omni in conjunction with the DME. The airport lies on a particular Omni radial from the VORTAC and will be located where the radial intersects the orbitting track.

DME operates in the 960 to 1215 MHz UHF range, transmitting in the range 960 to 1024 MHz and 1151 to 1213 MHz and receiving in the 1025 to 1150 MHz range.

Since the ground stations used by DME airborne equipment are usually VORTAC installations or DME ground stations collocated with VOR or with ILS facilities, DME channels are paired with VOR channels so that, when the pilot chooses on his DME equipment a VOR channel, he automatically chooses the UHF frequency as well. Channels on the DME channel selector are marked with the VOR frequencies even though it is controlling DME channels in the UHF MHz range.

The TACAN military installations can also be used to derive distance measurement. The TACAN stations are designated on navigation charts by channel numbers 1 through 126. The following chart shows how to translate a TACAN channel into megahertz in the VOR band.

MHz	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
108	17	18	19	20	21	22	23	24	25	26
109	27	28	29	30	31	32	33	34	35	36
110	37	38	39	40	41	42	43	44	45	46
111	47	48	49	50	51	52	53	54	55	56
112	57	58	59	70	71	72	73	74	75	76
113	77	78	79	80	81	82	83	84	85	86
114	87	88	89	90	91	92	93	94	95	96
115	97	98	99	100	101	102	103	104	105	106
116	107	108	109	110	111	112	113	114	115	116
117	117	118	119	120	121	122	123	124	125	126

For example: TACAN channel 80 pairs with 113.3 MHz.

DME equipment is considered reliable up to 100 miles from the station and is accurate within about 2%. Since UHF reception is dependent on line of sight, altitude is important in the efficiency of the equipment. The higher the altitude, the greater the effective range.

AREA NAVIGATION

COURSE LINE COMPUTER

With the capabilities of the Course Line Computer, precise off-airways, cross country navigation is possible using the present VORTAC facilities. The CLC permits a pilot to fly directly from any spot in the service area of a VORTAC to any other spot in that service area, at all times knowing his exact position and the distance to his destination. Neither his destination point nor his starting point need be serviced by any kind of navigational aid to use this system of "straight line" navigation. The pilot no longer needs to track to a VORTAC installation, cross it and track out, doglegging his way to his destination.

The area navigation airborne equipment consists of the computer, a CLC display, a CLC offset control head and a junction box which ties the system into the VHF nav receiver and the DME already installed in the airplane and which provide the required bearing and distance information to the computer.

To use the system, the pilot sets on the CLC offset control head the radial and distance from the VORTAC facility of the destination airport, waypoint or turning point. He then dials in the VHF frequency of the VORTAC facility on **both** the VHF receiver and the DME. Centering the Omni needle gives the bearing to the destination point. The distance to it is read off on the DME. The computer analyzes the signals from the ground station and continuously determines the aircraft's position with reference to them. The CLC display resembles the Omni/ILS Indicator; the Left-Right needle displays the off-course error in nautical miles and is accurate for a half mile error whether the aircraft is 1 miles or 60 miles from the station.

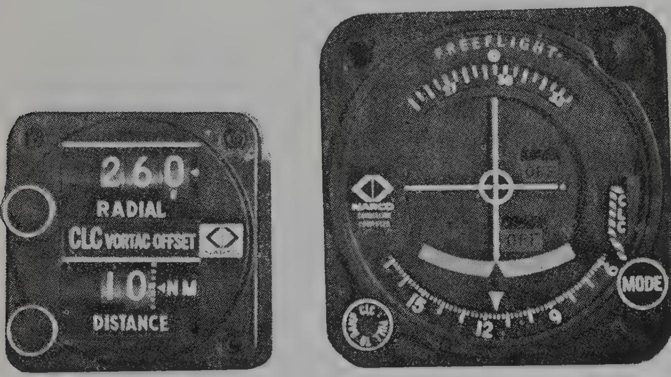


Fig. 24. Course Line Computer Offset Control Head and Display.

In Fig. 24, the button marked MODE on the CLC display is the selector switch for either CLC or Standard. On "CLC", the system will compute distances and direction to the chosen waypoint. On "Standard", the system will work the selected VORTAC station. On "CLC", the Left Right Indicator needle reflects Scalar Deviation, i.e. each dot represent 1/2 miles off course. On "Standard", the Left Right Indicator acts as a regular Omni Head display reflecting Angular Deviation and indicating degrees off course.

Because of the system's capability to bring the airplane directly over its destination, the CLC is invaluable in permitting flight to points that are not served by any kind of navigation aid, in finding airports in marginal weather. It permits straight line cross country flights over long distances. The pilot needs only to pick waypoints some 75 miles apart along his course and fly from one to the next using the CLC. Area Navigation greatly enhances air traffic control flexibility providing relief for some of the problems of air congestion and relieving some of the work load of air traffic controllers. It also contributes to air safety since it permits the pilot to choose a route that will bypass heavily congested areas and it reduces the funneling of traffic over navigation aids. It permits the establishment of multiple side by side routes between main centres and permits segregation of traffic on the basis of speed. The direct point to point navigation reduces flight time by shortening flight paths.

DOPPLER NAVIGATION

The Doppler Navigation System is another form of Area Navigation that enables the pilot to fly direct routes. Unlike the Course Line Computer which is dependent on ground based navigation aids, it is completely self-contained.

Doppler is a means of fixing the position of an airplane by methods somewhat similar to those used in D/R navigation, except that the plotting is automatically performed by electronic computers. Doppler provides the pilot with groundspeed, drift angle, distance travelled, present latitude and longitude, and deviation from desired track. The equipment is self-contained within the airplane and does not depend upon radio or radar aids of any kind on the ground.

Groundspeed is measured by a phenomenon that is known as the "Doppler Shift". Radar beams are directed from the airplane's transmitter towards the ground (Fig. 25.). Due to the forward motion of the airplane, when these beamed signals are reflected back to the receiver they have undergone a "shift", or change in frequency. The difference in frequency is proportional to the forward motion of the airplane and can therefore be used to accurately compute the groundspeed.

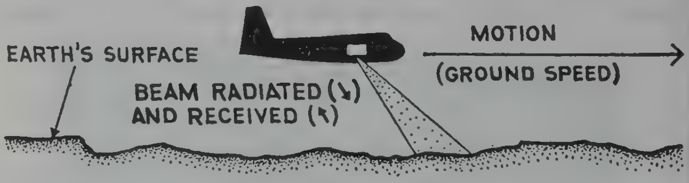


Fig. 25. "Doppler Shift." Beam radiated is bounced back on different frequency due to forward motion of airplane.

To measure drift, several beams are directed towards the ground to the right and left of the heading (or fore-and-aft axis) of the airplane. If the wind causes the airplane to drift, say, to the right, the Doppler Shift, or change of frequency experienced by the right beam will be greater than the left. The beams are now electronically rotated towards the right until the Doppler effect is equalized (which positions them symmetrically on either side of the track). The angle through which the antenna has to be turned is clearly the drift angle (Fig. 26.).

The equipment determines and indicates a continuous record of the airplane's groundspeed and drift angle. When the computer is incorporated into the Doppler, automatic solving of great circle tracks and distance is possible, and by "feeding in" heading information from the compass, the computer determines whether an airplane is off the desired track and, if so, indicates the distance off that track. These systems are not as yet "fool proof" and the computer must be "updated", that is, "corrected", occasionally during flight. Major airlines use this equipment extensively on transoceanic routes.

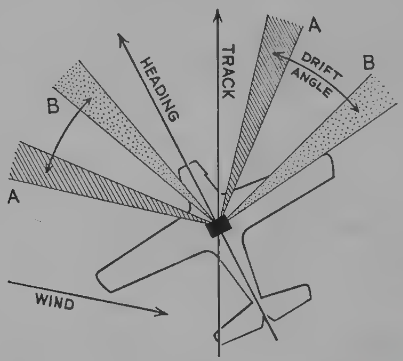


Fig. 26. A-A: Right and left beams in zero positon, assuming no drift. (Track would lie along same line as Heading.) B-B: Right and left beams after shifting due to drift to right.

The Collins Drift and Groundspeed Indicator (Fig. 28) is typical of the many types of Doppler instruments in use. Drift is indicated in degrees (right or left) by the pointer. Groundspeed is read directly below in knots. The Navigation Computer (Fig. 27) has two panels. While one is in use, the other can be set up for the next leg of the flight. STAGE A, the left hand panel, is set

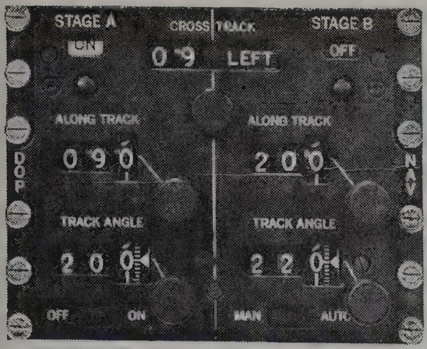


Fig. 27. Collins Navigation Computer Control Panel.

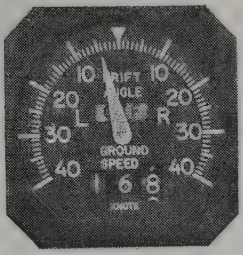


Fig. 28. Collins Drift and Groundspeed Indicator.

up for a Track of 200° and shows 90 miles to go. The CROSSTRACK indication at the top shows that the pilot is 9 miles to the left of his Track (possibly to detour around a storm). STAGE B, the right hand panel, which is not in use, has been set up for a Track of 220° and a distance of 200 miles.

INERTIAL NAVIGATOR

Inertial Navigator is a completely self contained system which, by use of a computer and accelerometers, can calculate the track to fly and distance between two points and, in flight, the distance an airplane is off that track. Presently in use in airline service, Inertial Systems are the basic long range navigational aid. Present equipment will automatically determine the direction of true north without use of a magnetic compass, display actual groundspeed, recalculate ETAs, and "store" several alternate destination positions. This equipment can also be used to determine and indicate an airplane's altitude.

LORAN

Loran is a basic navigational aid for transatlantic and transpacific flights.

The position of an airplane, or ship, can be determined by plotting position lines, each determined by measuring the time difference between signals received from two synchronized ground stations. Signals received are displayed on a Cathode tube. Special training in the use of the equipment, and a special map for plotting position lines, are required.

CONSOLAN

Consolan (or Consol) is a long-range navigational aid which requires only an airborne Low Frequency receiver capable of receiving on CW and fitted with a Beat Frequency Oscillator. The station radiates a series of 60 dots and 60 dashes in alternate sectors which are separated by a directional equi-signal (see Fig. 29). Since the whole pattern rotates clockwise in one half and anti-clockwise in the other, the number of dots and dashes heard will vary with the airplane's position in relation to the station. By counting the dots and dashes heard on either side of the equi-signal during a complete cycle of transmission, and referring the count to a chart or table, 12 lines of bearing will be indicated. The correct bearing of the airplane from the station is selected by checking it against the estimated DR position. Each Consolan Station transmits an identifying signal in code. The system is not usable when within 50 miles of the station. Two sectors, about 40° each, which are in line with the station antenna towers, are unusable. It is used for long range, over water navigation. Range is about 800-1000 miles by day, and about 1200 miles by night.

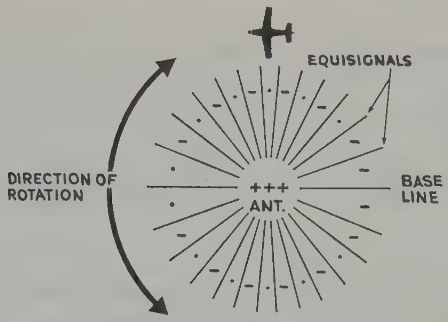


Fig. 29. Consolan Signal Pattern.

Position lines from two or more Consolan Stations will provide a fix.

OMEGA

The Omega Navigation System, originally developed by the U.S. Navy is a very long range, Very Low Frequency navigation system that works on a network of only 8 stations that operate with 10 kw transmitters. The 8 stations will give world-wide coverage.

Using the basic Omega system, an aircraft can fix its position to within about 1 mile during daylight or 2 miles at night. The reduced accuracy during darkness, characteristic of any low frequency radio navigation aid, results from diurnal changes in the Ionosphere.

A typical airborne Omega system includes a digital computer and a cockpit display. The crew can preset up to 10 waypoints and the indicator can display at the choice of the crew a variety of navigation data, including longitude and latitude data, bearing to destination, cross track deviation, distance to go, groundspeed and estimated time to waypoint.

The Omega system transmits a new set of signals every 10 seconds, rather than continuously as does a VORTAC.

It is prey to the disadvantages of all Very Low Frequency radio signals. It is subject to outrage if the aircraft is flying through thunderstorms with heavy electrical activity or in weather conditions that cause precipitation static. It is also subject to disturbance during solar storms which cause ionospheric disturbances.

On the other hand, because there are no line of sight limitations with low frequency, it is just as accurate in mountain valleys as in open plains. The VLF signals propagate to great range so that Omega will provide redundancy. In many locations, all eight stations will be detectable although perhaps only 5 or 6 will be usable.

For these reasons, the system is most useful if paired with an Inertial or a Doppler Navigation system. The accuracy of the Omega is useful to update such self-contained systems which are subject to error buildup during long endurance flights.

RADAR AND RADAR FACILITIES

The name Radar is an abbreviation of "Radio Detection and Ranging". To operate, radar requires a highly directional radio transmitter/antenna and a scope, or screen, to display the information received by the antenna.

The principal uses of radar in aviation are

1. Fixing positions of airplanes in flight.
2. Air Traffic Control.
3. Detecting thunderstorm activity.
4. Approach and landing guidance to airplanes (GCA).

Radar operates on the 3,000 to 10,000 MHz frequency band. Extremely short burst of super high frequency bursts of radio energy, called pulses, are fired into space along a **beam** from a highly directional radar antenna. These pulses strike airplanes, ships, buildings and other objects and are reflected back to the sender. The time it takes the pulse to travel to the reflecting object and return, is timed electronically in millionths of a second to determine the distance of the object from the sender. This information is displayed on the face of a cathode ray tube, called an oscillioscope, or more commonly a scope or screen. The information appears in the form of a small **blip** of light that is called a **target.**

At the centre of the scope is the radar antenna. The scope is marked with concentric rings (called range markers) that measure distance from the antenna (Fig. 30). An azimuth scale is marked around the circumference of the scope (not shown in Fig. 30). The controller working the scope is thus able to determine the bearing and distance of a target representing an airplane.

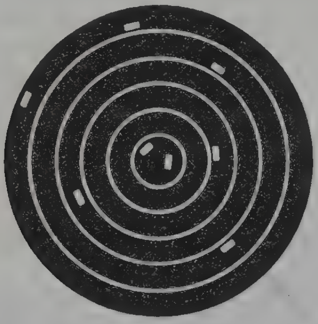


Fig. 30. A Radar Scope.

The beam, transmitted by the radar transmitter and called in radar terminology a **trace,** will pick up only objects towards which it is pointed directly. In order to "see" objects around the entire horizon from the sender's position, the beam is rotated through 360° by a scanner at a constant rate of speed. A sweep line on the scope is synchronized with the rotation of the antenna. The target that appears on the scope fades out after the sweep line passes, but reappears again as the sweep line passes on its next rotation. As a result, the track of an airplane can be seen on the radar scope.

Radio waves travel at a rate of 186,000 miles per second. To measure them, the unit of time used is the **Microsecond,** which is one millionth of a second.

Pulses of electromagnetic energy are beamed out to the target and reflected back (Fig. 31). The signal which is reflected back is called an **Echo.** It takes 10.75 microseconds for a signal to travel one mile out to a target and for the echo to return. The round trip distance is known as a **Radar Mile.**

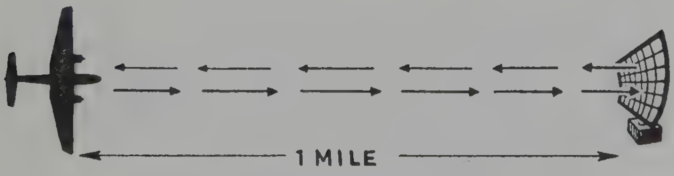


Fig. 31. Distance Measuring by Radar.

The use of radar in ATC procedure greatly increases utilization of the airspace and permits expansion of flight information services such as traffic and weather information and navigational assistance.

There are two basic types of Radar Systems.

1. **Primary Surveillance Radar:** Primary radar is based solely on the echo principle and requires no equipment in the airplane. Three types of primary radar are in use by ATC units.

(i) Airport and Airways Surveillance Radar (AASR) — a medium range radar designed for both airway and airport surveillance applications.

(ii) Airport Surveillance Radar (ASR) — a relatively short range radar intended primarily for surveillance of airport and terminal areas. (See below)

(iii) Precision Approach Radar (PAR) — a short range radar used as an approach aid. (See below)

2. **Secondary Surveillance Radar:** Secondary Surveillance Radar (SSR) requires complimentary aircraft equipment.

SECONDARY SURVEILLANCE RADAR

Although radar is a very valuable asset to the Air Traffic Control system, it has several disadvantages.

In heavy traffic areas, all the targets on the radar scope look the same. There is no way a controller can distinguish between two targets in the same general area. He must ask one of the airplanes to take up a specific heading and then wait to see which target on the screen reacts to the instruction in order to make an identification.

The signal directed to low flying airplanes often experiences interference from terrain features, buildings, etc. As a result the echo is weak.

Precipitation also returns echoes.

To overcome these disadvantages of the primary radar system, a secondary surveillance radar system was developed. It requires airborne equipment that returns a strong signal to the primary radar transmitter. As a result, the target on the radar scope is stronger and more readily identified by the controller.

The airborne equipment is called a **Transponder.**

TRANSPONDER

Designed to reinforce a surveillance radar signal, the transponder permits positive identification of an aircraft by the ground facilities of ATC. A typical airborne transponder system includes a control, a receiver/transmitter and a small L-bank antenna mounted on the underside of the aircraft. Ground equipment consists of a transmitter/receiver and a rotating directional antenna that usually is mounted on top of the regular surveillance radar antenna.

The transponder works like this. The ground radar equipment sends out a special interrogation signal asking all aircraft, "Who are you?" Only transponder equipped aircraft can answer. The airborne transponder picks up the signal and automatically sends back a strong pulsed signal in reply. The reply signal is computed into distance and direction (and into altitude on Mode C) by the ground radar station and is displayed with the aircraft's target on the traffic controller's scope as one or two slashes.

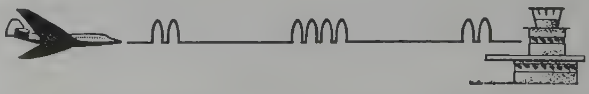


Fig. 32. Pulse signals between airplanes and ground station (either way) moded and coded for signal identification.

The interrogation signals from the ground radar are **moded.** Mode A asks for identification. Mode C requests altitude information. Pilots adjust their sets to the appropriate mode. On transponder controls used in general aviation, mode selection of A or A/C is provided. On Mode A, the transponder automatically replies to all interrogations. When the mode selector is placed in the A/C position, the transponder provides proper identification plus altitude information.

In order that altitude information can be encoded by the airborne transponder and relayed to ATC, an encoding altimeter must be installed in the airplane and linked into the transponder equipment. At some of the major airports in North America, only airplanes equipped with transponders capable of reporting altitude information are now permitted to operate.

In the transponder shown in Fig. 33, the Mode A selection is automatically selected when the set is activated. Mode C selection is made by selecting ALT.

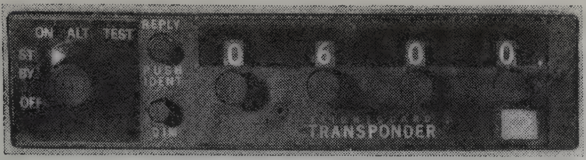


Fig. 33. Narco Transponder.

The reply signal sent by the airborne transponder is **coded.** Specific codes are assigned by an air traffic controller on the ground for various flight levels and conditions of flight. The pilot selects this code on the control in his cockpit.

Most transponders have 4096 code capability. All transponder codes are, therefore, 4 digit codes. In Fig. 33, the code 0600 has been selected. The controller can identify the various code settings assigned to different flight requirements.

In assigning codes, for example, Arrival Control at a particular ATC Centre may use 4700 while Departure Control will use 2400. One ATC Centre in handing a flight over to another Centre will ask the pilot to select the code of that centre. A pilot on a VFR flight plan may select 1200 (below 10,000 feet) or 1400 (above 10,000 feet) on his transponder control. This will automatically inform the ATC radar controllers that the aircraft is a VFR flight and they will be able to maintain positive separation of their IFR and VFR traffic.

In the event of an emergency and if unable to establish communication immediately with an ATC unit, a pilot wishing to alert ATC to his situation should select Code 7700.

In the event of a communications failure, the transponder should be adjusted to reply on Code 7600, in order to alert ATC to the problem.

On an IFR flight plan, the loss of all radio communication ability necessitates termination of the flight at the first convenient airport. The versatility of the transponder can be seen in the situation in which the communications problem affects only the transmitting capacity. A flight, on an IFR clearance, can be continued by using the transponder as a transmitting device. The ATC controller is able to ask questions and give instructions in normal fashion; the aircraft acknowledges these transmissions by ‘‘Squawking Ident’’.

If the controller decides to verify his ‘‘target’’ when more than one aircraft are on the same code, he will call the pilot and ask him to ‘‘Squawk Ident’’. When the pilot presses the Ident button on the transponder control, a special signal is sent out that causes the target to ‘‘blossom’’ on the controller’s scope. The target will blossom for a few seconds and then return to its regular pattern. The ‘‘IDENT’’ feature should be operated only when directed by ATC.

Most controls have a function tester or small reply light which blinks every time the transponder replies to a ground interrogation signal, letting the pilot know that the transponder is operating.

Normally the transponder is operated in the ‘‘ON’’ position. The control also has a ‘‘low’’ selector that reduces the intensity of the reply signal when the aircraft is nearing the station.

ATC radar units are equipped with an alarm system that is triggered when an aircraft within its radar coverage has selected the emergency, communication failure or unlawful interference transponder codes. It is possible for those codes to be momentarily and unintentionally selected while the aircrew is changing from one code to another. To avoid unnecessary activation of the alarm system at ATC, transponders should be adjusted to ‘‘standby’’ immediately prior to making a code change. After the new code has been selected, ‘‘normal’’ operation should be resumed.

Transponders should be adjusted to ‘‘standby’’ while taxiing for take-off, to ‘‘on’’ as late as practicable before take-off, and to ‘‘standby’’ or ‘‘off’’ as soon as practicable after landing.

Transponder Phraseology

Air traffic controllers use certain phraseology when referring to the operation of transponders.

Squawk (code) — Operate the transponder on the specified code.

Squawk Ident — Push the IDENT button.

Squawk Standby — Switch transponder to ‘‘standby’’ position.

Stop Squawk — Switch off transponder.

ENCODING ALTIMETER

With advances in the technology of radar equipment, altitude information can now be relayed by the airborne transponder equipment to the ATC radar display for the information of controllers. The instrument that feeds the altitude information into the transponder is known as an encoding altimeter.

There are two basic types of encoding altimeters — the pneumatic or mechanical type and the servo type. The pneumatic type is essentially a conventional barometric altimeter with an encoding device that converts altitude into digitally coded electrical signals in 100 foot increments. These signals are wired to the transponder which, when set to Mode C, are transmitted as replies to the ‘‘What’s your altitude?’’ interrogation of ground radars. It uses evacuated capsules called aneroids to sense altitude — by expanding and contracting with static pressure. The movement of the aneroid walls, via gearing, drives the altimeter pointers for visual display. At the same time, the pressure of the moving aneroids drives a small glass disc providing the electrical signal to activate the encoding device.

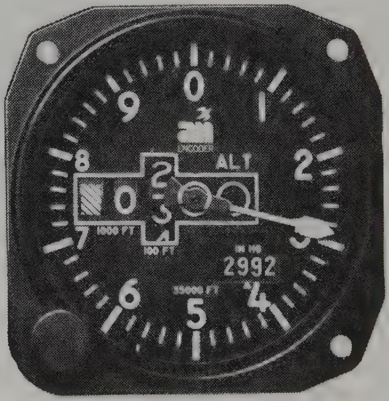


Fig. 34. Encoding Altimeter.

The servo type of encoding altimeter also uses the aneroid system to sense altitude but the power to drive the encoding and display mechanism is derived from the airplane’s electrical system. The servo type, having an outside source of power, can drive pointers and encoders and at the same time provide ancillary outputs for an altitude alerter, rate of climb indicator, vertical nav system and auto-pilot. The servo type encoding altimeter is very accurate and very reliable. Its disadvantage is its complete dependence on electrical power to operate.

GROUND CONTROLLED APPROACH (GCA)

The Ground Controlled Approach (GCA) system is a method of guiding a pilot on instruments down to the runway for a landing by means of verbal instructions from a controller working a primary surveillance radar system such as ASR or PAR.

GCA requires no special equipment other than a radio transceiver and normal flight instruments, and can be requested by a private pilot who may have become lost or accidentally caught in instrument weather conditions.

The radar operator on the ground can ‘‘see’’ the plane in the radar scanning screens (Fig. 35) which he has in a panel before him. Lines and circles on the scanning screens provide the radar operator with azimuth, range and altitude data which enables him to guide the pilot down to the runway of the airport.

ASR (AIRPORT SURVEILLANCE RADAR)

ASR is a relatively short range radar that gives surveillance of the immediate area surrounding the airport. The ASR scope provides range and azimuth information only. The pilot may be directed to a selected runway, but must judge his own descent, based on the distance information furnished him by the controller.

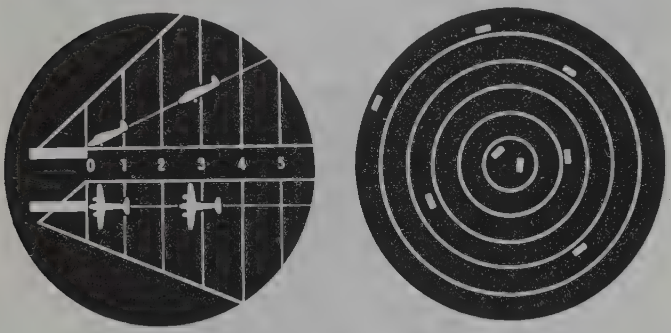


Fig. 35. GCA Scanning Screens.

Right: The SURVEILLANCE or ASR SCOPE. Circular lines are 5 miles apart. The "blips" are airplanes. The radar surveillance antenna, rotating through 360°, scans a radius 30 miles out and 10,000 feet up. Positon of every airplane within a 2,800 square-mile area is continously shown on the surveillance scope.

Left: The PAR (PRECISION APPROACH RADAR) SCREEN: Exact position of the aircraft is constantly shown on the screen in three dimensions — altitude, azimuth and range. (The airplane silhouettes have been sketched in to make the principle more easily understood. In actual practice the airplanes appear as "blips", the same as in the illustration on the right.) The PAR operator has two such scopes, one covering a 10-mile area, and the other a 3-mile area. The latter is scaled up to provide greater precision on final approach. The equipment is accurate to within plus or minus ten feet.

Note: If a GCA unit has been inoperative, it requires 20 to 30 minutes to warm up. A pilot requiring GCA should therefore try to alert the facility as far in advance as possible.

PAR (PRECISION APPROACH RADAR)

PAR guides the airplane to final approach on the designated instrument runway. In addition to azimuth and range information, it furnishes the pilot with glide path assistance down to the point of touch down on the runway.

TO USE GCA

To request GCA assistance if you are flying VFR, call the Tower. State your approximate position as accurately as you can, and your altitude. The Tower will assign a transmitting and receiving frequency for communication with the GCA controller. GCA will then request you to execute a few simple turn maneuvers or, if you are transponder equipped, GCA will ask you to "Squawk Ident". This is for positive identification of your airplane on the scanning screen. At this point the controller may give you *Lost Communications* instructions as follows:

Controller: **If you lose Radio Contact for any 5 second interval, maintain VFR and contact the Tower on . . . . . MHz (Tower frequency) for Secondary instructions.**

If you are lost under VFR conditions, the Surveillance Approach (ASR) controller will give you a heading to steer to bring you to the runway, and will continue to vector your approach in case you happen to stray from the required track.

If the visibility is marginal and it is necessary to make a landing under instrument conditions, you will be given Precision Radar navigation assistance to guide you at a safe altitude, into the traffic pattern and on to the base leg. At this point you will be requested to check your gyro compass and not to reset it during the remainder of the approach. In case your gyro isn't working, advise the controller immediately. He will give you a "no gyro" approach and will probably brief you as follows:

Controller: **This will be a No Gyro Precision Approach. Runway One Three. Make Standard Rate Turns. Execute Turn Instructions on Receipt.**

Obey the instructions implicitly, using the needle of your turn and slip indicator as your turn reference. Do **not** attempt to make corrections on your own.

On base leg, as you are about to intercept the final approach leg, the PAR controller will take over and turn you on to the correct heading to line you up for final approach to the selected runway. As you intercept the glide path you will be given the correct rate of descent to maintain. Instructions will be simple.

Controller: **You are now on Final Approach for Runway One Three. Six Miles from Touch down.**

Once the descent has started, if the approach is normal, the controller will merely give you distance, steering and glide path checks. For example:

Controller: **Three Miles from Touch down. You are on Course. On the Glide Path.**

Should you get off the line of approach or glide path, he will advise you of the deviation and give you the necessary correction. For example:

Controller: **Four miles from Touch down. 200 Feet to the Left. Turn Right. Heading One Three Six.** Followed by, **You are on Course.** Or **You are 50 Feet above the Glide Path. Ease it Down.** Followed by, **You are on the Glide Path. Adjust your Rate of Descent.** As you near the threshold of the runway, he will caution you, **Wheels Down and Locked.** When you reach it, he will advise you, **Over the End of the Runway. Take it Visually.** You are then cleared to take over and land.

EMERGENCY LOCATOR TRANSMITTER

An Emergency Locator Transmitter is a battery operated radio transmitter that sends out a distinctive distress signal on the international emergency frequency 121.5 MHz. The sending mechanism is activated by the force of the impact experienced during a crash.

The transmitter is constructed to survive a crash and to transmit a signal through a temperature range from 25°C to 40°C below zero for a period of at least 100 hours. The ELT is activated if subjected to a force of 5 to 7 gs for 11 milliseconds.

Most Canadian aircraft are required to have an approved ELT installed. Those exempted are those aircraft which operate only within 25 miles of their home airport, multi-engine and jet airplanes that operate only in controlled airspace, gliders, balloons.

The ELT has been proven to reduce significantly the time necessary to locate a downed aircraft, thus substantially improving the chances of survival of injured crew and passengers.

As well as the type of ELT that is installed in the airplane and is activated automatically by the impact of a crash landing, there is also a portable hand held type of ELT that is operated manually. Installation of the former type is mandatory but many pilots feel that having the portable ELT aboard as well is an extra precaution.

The ELT will only do its job, however, if it has been "armed". The transmitter has a three position switch — ON, OFF and ARMED. Arming the ELT should be part of the pre-flight check. Turning it off should be part of post flight shut down procedures.

Inadvertent activation of ELTs has been a problem and it is recommended that all pilots operating aircraft with this equipment installed listen on the ELT frequency immediately prior to shut down to ensure that the ELT has not been activated.

The ELT is a battery operated transmitter. Pilots must bear in mind that the battery must be replaced at or about the expiration date marked on the battery.

Testing of an ELT may be carried out in the first 5 minutes of each hour. A maximum 3 audio sweeps taking about 2 seconds is all that is necessary to determine that the ELT is in good operating condition. Longer testing can result in false alarms being registered with ATC.

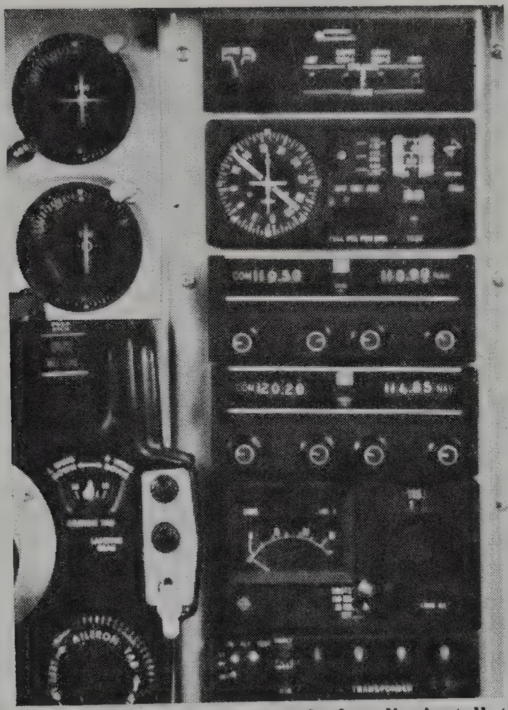


Fig. 36. Pictured above is the stacked radio installation in a typical modern airplane. The navigation and communication equipment includes, from top to bottom, an ADF, two VHF transceivers with OMNI head indicators to the left, DME and transponder.

Airmanship - - -

Airmanship is proficiency in the handling and operating of airplanes on the ground and in the air. It involves understanding of the necessity and care in the execution of keeping an airplane in airworthy condition. A proficient pilot is fully conversant with the capabilities of his airplane and understands and regularly refers to the flight performance charts in the Airplane Flight Manual. He understands the principle of weight and balance and knows how to load an airplane properly. He knows how to plan and carry out a cross country flight proficiently, how to avoid wake turbulence, how to make good landings, how to deal with emergencies, etc. This chapter is designed to introduce a pilot to the concepts involved in good airmanship and whet his appetite to seek further information and experience in broadening his proficiencies as a pilot.

CARE OF THE AIRPLANE

The wise pilot carefully and systematically supervises the inspection, maintenance, and servicing of his airplane. "Air mechanics are, on the whole," he observes, "more precise, painstaking and conscientious about their work than is the average pilot. They are, however, only human beings and as such are not infallible. They could forget to clean the filter or fit a split-pin, or ground the airframe while refuelling. It pays a pilot to check every detail himself before taking an airplane off the line."

AIRPLANE CLEANLINESS

Dirt covers defects, making them more difficult to detect. Dirt also increases skin friction, detracting from the performance of the airplane.

Dead insects commonly found on the leading edge of wings and propeller blades cause drag and should be removed to assure maximum aerodynamic efficiency. This is a "sensitive" area and should be extremely smooth at all times if the manufacturer's performance figures are to be realized. (The manufacturer obtained his performance calculations in a "clean" airplane). Therefore, keeping an airplane clean is very important.

EXTERNAL AIRFRAME

For washing airplanes, use mild detergent soaps and water. Linseed soap is an "approved" soap for fabric covered airplanes and, when properly used (after surface is dry, rub down with a soft dry cloth as if to shine), it has the advantage of leaving a thin film which makes the surface "slippery" and thereby helps to reduce drag. Remove mud with water. Never use gasoline as a cleaning fluid.

Be sure that drain grommets located at the lowest points in wings, fuselage and control surfaces are not clogged with dirt or foreign matter. If these are clogged, water is prevented from draining away; moisture left sitting in the interior of the airframe tends to start corrosion and rot. Ventilation, especially important in wood and fabric structures, will also be hampered if the drain grommets are clogged.

Varsol is the approved cleaning fluid for removing oil and grease from engines, firewalls, cowlings and all external surfaces including the underside of the fuselage which is most susceptible to collecting grime.

Metal airplanes are susceptible to corrosion and must be kept scrupulously clean to prevent corrosion. Cleaning agents which do not contain abrasive compounds should be used. Wax applied to metal surfaces prevents oxidation and reduces the amount of cleaning and polishing required.

Visibility is much better through a clean windshield than through a dirty one. Windshields should be cleaned and polished with special non-abrasive liquid cleaners made especially for this purpose.

INTERIOR

Dirt and dust in the fuselage increase weight and add to the fire hazard.

Keep the interior of the cabin and fuselage free of dirt and foreign material. Use a vacuum cleaner on floor areas often. Be extremely careful when cleaning upholstery as it may have been treated with fire resistant chemicals and this protection should not be removed; follow the manufacturer's recommendations.

Spilt acids, chemicals, fire extinguisher fluids, etc. should be reported as they could cause corrosion and weakness of the structure.

Dirt falling beneath the floor where control pulleys and connections are located can cause wear of the bearing surfaces and lead to incorrect operation. Dirt and dust may also interfere with proper operation of electrical switches.

PROPELLERS

Propellers should be kept clean. As these are rotating airfoil sections, what applies to wing cleanliness applies also to them. They should be kept clean of dead insects, grass and dirt. A clean and waxed propeller will actually produce a higher rpm at full power settings than one that is dirty.

CARBURETOR AIR FILTER

Inclined to be overlooked by pilots between scheduled maintenance inspections is the condition of the carburetor air filter. It should be kept clean of bugs, plant seeds, dust and dirt at all times. One of the most frequent causes of premature engine wear is a dirty air filter. Constant attention to the cleanliness of this part will assure many additional hours of running before an engine overhaul becomes necessary.

EXHAUST HEATERS

Cabin heaters which obtain heat from the exhaust system should be inspected at frequent intervals for leaks which might allow carbon monoxide fumes to enter the cabin.

GROUND HANDLING OF THE AIRPLANE

Tricycle geared airplanes are most easily and safely maneuvered, during ground handling, by the use of a tow-bar attached to the nose wheel; therefore, it is recommended that one be used whenever possible. When moving tricycle geared airplanes by hand when no tow-bar is available, push down at the point where the stabilizer attaches to the fuselage in order to raise the nose wheel. The airplane can then be turned by pivoting it about the main gear.

On both tail wheel and tricycle geared airplanes, when moving a high wing airplane forward or backward by hand, push at the wing strut root fitting or at the main landing gear strut. Low wing airplanes are most easily pushed backwards by hand by pushing against the leading edge of the wing; the wing tips may be used to help maneuver the airplane.

PICKETING AN AIRPLANE OUTDOORS

1. Park the airplane in a sheltered location, such as behind a row of trees or buildings, etc. (However, parking beside a

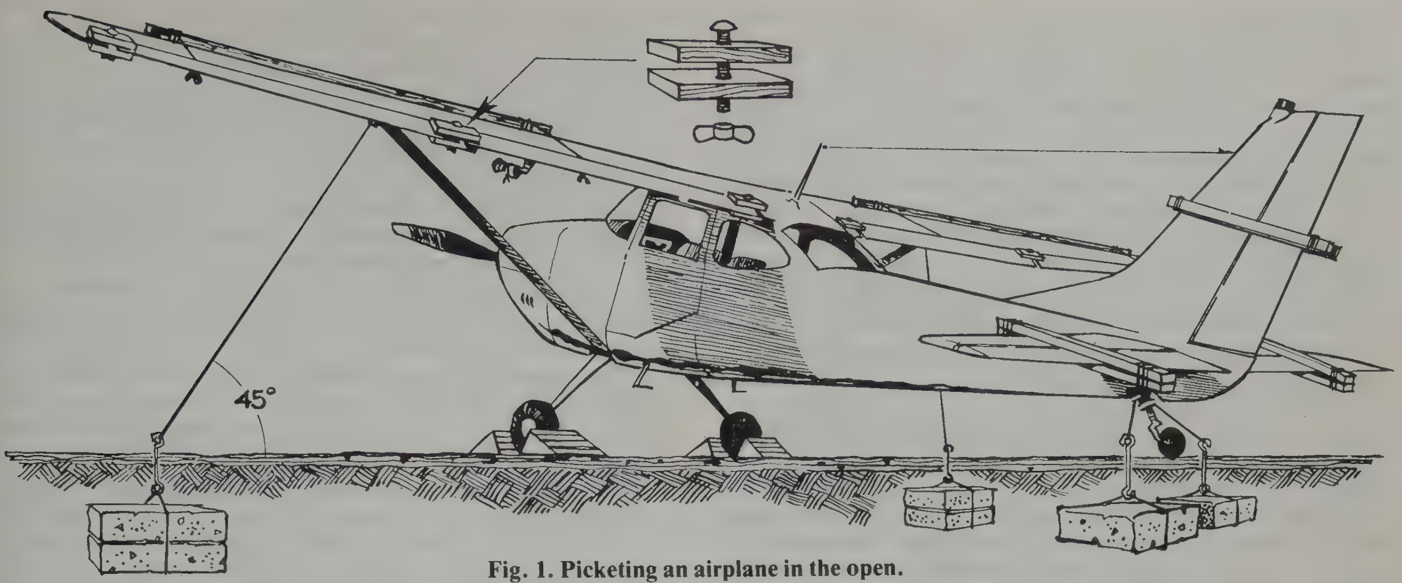


Fig. 1. Picketing an airplane in the open.

bulding is not recommended in winter since ice falling from the roof could damage the airplane.)

2. Head the airplane into the prevailing wind.
3. Use external control locks to hold the ailerons, flaps, elevators and rudder in the neutral position to prevent damage occurring to control surfaces. (Cockpit control surface locks are not recommended for continuous outdoor storage as gusts can still exert pressure on the various control surfaces and stretching of the control wires will result.)
4. Place chocks behind and in front of all wheels.
5. Fasten ropes to appropriate places on the wings and fasten to weights buried in the ground. Stakes, pegs or corkscrews are not recommended. If the ground becomes saturated with rain they will easily pull out.
6. Cover the engine and cabin with a tarpaulin, polyethylene, canvas, etc. to prevent dust from entering the engine where it might cause excessive wear, birds from building nests, etc. The covering over the cabin will prevent rain from entering and causing corrosion and general deterioration. Cover the pitot tube.
7. In very cold weather, drain the oil into a clean container while it is still warm.
8. Place a "spoiler" spanwise over the top of the wing about 20% back from the leading edge. Such a spoiler will prevent lift from being developed. A "2 x 4" piece of lumber held in place by a light rope looped around the wing cordwise is an effective spoiler.

REFUELLING

Always ground the airplane and hose nozzle when refuelling, owing to danger of fire from static electricity.

The nozzle should make metal to metal contact with the filler neck of the fuel tank that is being filled.

Only fuel of the octane rating specified by the engine manufacturer should be used.

Tanks should be filled immediately after flying. Water vapour in the air in an empty or partially filled tank will condense and cause water contamination of the fuel.

Do not completely fill the tanks with cold fuel if the airplane is to be stored in a warm hangar. Aviation gas will expand about ½% in volume for a 5°C rise in temperature.

Never pump fuel from the bottom of a drum. The pump intake pipe should be made shorter than the depth of the drum by approximately 1 inch. Do not pump fuel from a drum which has just been moved around. Let the drum stand for some time to allow any water or dirt to settle to the bottom. Unless a more efficient filter is available, refuelling from drums should be done through a chamois filter and funnel. Use a chamois of good quality only and replace it frequently. Any reduction in the flow through the chamois should be reason to suspect water contamination. Never wring a chamois free of water. This nullifies the water-separation properties of the chamois.

Never prime a fuel pump with water to make it work.

During the inspection of the airplane prior to flight, a reasonable quantity of fuel should be drawn from the lowest point of the fuel system into a glass container. Water is heavier than gasoline and will settle to the bottom, where it can be readily detected.

If there is any suspicion that water exists in the airplane fuel system, the entire system should be thoroughly checked.

Only oil of the S.A.E. number or grade specified by the engine manufacturer should be used. The manufacturer usually recommends different oils for varying climatic conditions.

Oil should only be changed in accordance with the recommendation of the engine manufacturer.

The oil tank should never be filled to the top. Leave room for the expansion of the oil when it gets hot.

WINTER OPERATIONS

Flying in the wintertime necessitates extra precautions on the part of the pilot. Snow, ice and cold weather create problems that the pilot who flies only in the summer never has to worry about.

For example, blowing snow can enter pitot tubes, fuel tank vents, airscoops, wheel wells and any other uncovered openings, while the airplane is parked, and freeze solid causing malfunctions of the parts affected.

If the drain holes in the airframe are clogged, water that gets inside the structure will be trapped and will freeze. Ice can jam the controls, throw the weight and balance off, crack the airframe and interfere with proper venting. Inspect the drain holes regularly to be sure they are open.

Water in the fuel lines will at any time of year affect engine performance but during the winter it poses the added problem of perhaps freezing and blocking the lines. Refuel after each flight to help prevent condensation and in addition drain a substantial amount of fuel from the lowest point of the fuel system before each day's flight and after each refueling.

Since cabin heaters will be in regular use during winter operations, it is essential to ensure that the cabin heater system is free of cracks or holes. Small amounts of carbon monoxide affect judgment and flying ability. Large amounts can be lethal.

Remove all frost, snow and ice from the wings and control surfaces of the airplane before take-off. Even a small amount of frost will sufficiently alter the lifting characteristics of the airfoil that the airplane's take-off capabilities will be substantially affected. The roughness of the frost covered surface spoils the smooth flow of air over the airfoil causing loss of lift and early stall. Tests have shown that frost on the wings of a conventional light airplane has increased the stalling speed by at least 5 to 10% and even as much as 30% and the take-off distance by as much as 100%. In one test, a ski-equipped STOL airplane with frost on the wings could not reach a speed at which it could take-off even though a large lake was available for the take-off run. Never assume that snow will blow off. Always clean off any accumulation and be sure the wings are clean before getting underway.

Regularly check the carburetor heat control to ensure that it is operating properly throughout its entire range. Be sure also that the carburetor temperature gauge is working properly and is giving true indications. It is your ice warning device. During cold weather operations, when checking proper operation of the carburetor "hot air" control as part of the normal pre-take-off check, allow the engine to run for a few seconds with the heat control "full on" to assure that any ice that may have formed in the carburetor venturi area during taxiing and warm-up will be eliminated.

Retractable landing gears and wheels equipped with "wheel pants" can become clogged by the mixture of ice, slush and mud that is thrown up during landing and taxiing. Be sure the landing gear is clean and capable of spinning freely. Check strut extensions and tires for proper inflation. Extreme cold temperatures may require reservicing them. During take-off, more slush and mud will be thrown on the landing gear and may freeze solid after the gear is retracted. To prevent this, delay retracting the gear for a moment or so to allow the slipstream to blow off most of the slush.

Be sure de-icing equipment is operational and know how and when to use it. The problems of ice accretion have been discussed more fully in the Chapter **Meteorology**.

Above all, do not hurry your pre-flight inspection because of the discomforts of the cold weather. Be even more thorough than you would normally be.

Be sure that you have carefully studied the handbooks pertaining to your airplane, understand all the systems of the airplane and know the recommended winter operation procedures.

It is important to conduct your preflight planning with care, so that your flight can be carried out safely within the limitations of both the weather and your abilities as a pilot. Winter operations mean fewer hours of daylight, snow showers that completely and suddenly obscure the terrain, whiteout conditions, icy runways, etc.

Special procedures for the operation of the engine in cold weather have been discussed in the Chapter **Aero Engines.**

WEIGHT AND BALANCE

A pilot is responsible for the safe loading of his airplane and must ensure that it is not overloaded. The performance of an airplane is influenced by its weight and overloading it will cause serious problems. The take off run required to get the airplane airborne may be greater than the available runway. The additional weight may cause structural stresses during maneuvres and turbulence that could lead to damage.

The Total Gross Weight authorized for any particular type of airplane must therefore never be exceeded. A pilot must be capable of estimating the proper ratio of fuel, oil and payload permissible for a flight of any given duration.

The distribution of weight is also of vital importance since the position of the Centre of Gravity affects the stability of the airplane. In loading an airplane, the C.G. must be within the permissible range and remain so during the flight to ensure the stability and maneuvrability of the airplane during flight.

Airplane manufacturers publish weight and balance limits for their airplanes. This information can be found in two sources:

1. The Aircraft Weight and Balance Report.
2. The Airplane Flight Manual.

The information in the Airplane Flight Manual is general for the particular model of airplane.

The information in the Aircraft Weight and Balance Report is particular to a specific airplane. The airplane with all equipment installed is weighed and the C.G. limits calculated and this information is tabulated on the report which accompanies the airplane log books. If alterations or modifications are made or additional equipment added to the airplane, weight and balance must be recalculated and a new report prepared.

WEIGHT

Various terms are used in the discussion of the weight of an airplane. They are as follows:

Weight Empty: The weight of the airframe and engine with all standard equipment installed.

Extra Equipment: Any and all additional instruments, generators, radio equipment, etc., installed but not included as "standard equipment", the weight of which must be deducted from the payload.

Basic Weight: The weight of the airplane with all special equipment included is sometimes referred to as the basic weight.

Disposable Load: All load which is removable, that is, which is not permanently part of the airplane. It includes the fuel and oil, pilot, crew, passengers, baggage, freight, etc.

Payload: The load available as passengers, baggage, freight, etc., after the weight of pilot, crew, fuel and oil have been deducted from the disposable load.

Gross Weight: The all-up weight of the airplane fully loaded.

Passenger Weights: When the actual weights of individual passengers are not known, the following averages may be used:

Adult Male	165 lb.
Adult Female	143 lb.
Child (3 to 11 yrs)	77 lb.
Infant	22 lb.

Fuel and Oil: The Airplane Flight Manuals for airplanes of U.S. manufacture give fuel and oil quantities in U.S. gallons. Conversion to Imperial gallons, therefore, is necessary when operating in Canada. Multiply U.S. gallons by 5/6 to obtain the equivalent number of Imperial gallons.

Fuel	Imp. Gal. - 7.2 lb.	U.S. Gal. - 6.0 lb.
Oil	Imp. Gal. - 9.0 lb.	U.S. Gal. - 7.5 lb.
Jet Fuel A	Imp. Gal. - 8.7 lb.	
Kerosene	Imp. Gal. - 8.25 lb.	U.S. Gal. - 6.7 lb.

Maximum Landing Weight: Most multi-engine airplanes which operate over long stage lengths consume a considerable weight of fuel. As a result, their weight is appreciably less on landing than at take-off. Designers take advantage of this condition to stress the airplane for the lighter landing loads, thus saving structural weight. If the flight has been of short duration, fuel or payload may have to be jettisoned to reduce the gross weight to Maximum Landing Weight.

Maximum Weight — Zero Fuel: Some transport planes carry fuel in the wings, the weight of which relieves the bending moments imposed on the wings by the lift. The Maximum Weight — Zero Fuel limits the load which may be carried in the fuselage. Any load added beyond the max. zero fuel weight must be in the form of fuel.

Float Buoyancy: The maximum permissible gross weight of a seaplane is governed by the buoyancy of the floats. The buoyancy of a seaplane float is equal to the weight of water displaced by the immersed part of the float. This is equal to the weight the float will support without sinking beyond a predetermined level (draught line).

The buoyancy of a seaplane float is designated by its model number. A "4580" float has a buoyancy of 4580 lb. A seaplane fitted with a pair of 4580 floats has a buoyancy of 9160 lbs.

Regulations require an 80% reserve float buoyancy. The floats must, therefore, have a buoyancy equal to 180% of the weight of the airplane.

To find the maximum gross weight of a seaplane fitted with, say 7170 model floats, multiply the float buoyancy by 2 and divide by 1.8.

$$(7170 \times 2) \div 1.8 = 7966 \text{ lb.}$$

COMPUTING THE LOAD

A typical light airplane has a basic weight of 993 lb. and an authorized gross weight of 1600 lb. An acceptable loading of this airplane would be as follows:

Basic Weight		993 lb.
Consisting of Weight Empty	973 lb.	
Extra Equipment	20 lb.	
Disposable Load		607 lb.
Consisting of Pilot	165 lb.	
Fuel	146 lb.	
Oil	15 lb.	
Payload: Passenger	165 lb.	
Baggage	116 lb.	

Problem

To find the maximum payload that can be transported a given distance and the amount of fuel required.

A de Havilland Beaver seaplane is required to transport a maximum load of freight a distance of 350 miles. The estimated groundspeed is 124 mph, cruising at approximately 53% of power. The disposable load is 1836 lb. Fuel capacity is 72 Imp. gal. Oil capacity is 5 Imp. gal. Fuel consumption is 16.7 gal/hr or 120 lb. of fuel per hour.

The time to fly 350 miles is 169 minutes (350 ÷ 124 × 60). Add to that the 45 minutes required for reserve and the amount of fuel required must be sufficient for 214 minutes of flying time.

The amount of fuel required at 16.7 gal/hr is 59.5 gal. (16.7 ÷ 60 × 214). That quantity of fuel weighs 428 lb. (59.5 × 7.2 lb).

The fuel calculations can also be computed by using the weight of fuel consumed per hour. The weight of fuel necessary for the flight is 428 lb. (120 ÷ 60 × 214).

The disposable load is 1836 lb. The weight of the pilot (165 lb.), fuel (428 lb.) and oil (5 gal. at 9 lb/gal or 45 lb.) is 638 lb.

Therefore, the maximum payload permissible is 1198 lb.

BALANCE LIMITS

The position of the Centre of Gravity affects the stability of the airplane. If it is too far forward, the airplane will be nose heavy, if too far aft, tail heavy. An airplane whose Centre of Gravity is too far aft may be dangerously unstable, and will possess abnormal stall and spin characteristics. Recovery may be difficult if not impossible because the pilot is running out of elevator control. The stabilizer and elevator of an airplane are designed to lift a certain amount of weight and if this load is exceeded due to too far aft location of the C.G., control of the airplane in the pitching plane will be lost. It is the pilot's responsiblity when loading an airplane to see that the C.G. lies within the recommended limits.

Usually the Airplane Owner's Manual lists a separate weight limitation for the baggage compartment in addition to the gross weight limitation of the whole airplane. This is a factor to which the pilot must pay close attention for overloading the baggage compartment (even if the plane itself is not overloaded) may move the C.G. too far aft and affect longitudinal control.

As the flight of the airplane progresses and fuel is consumed, the weight of the airplane decreases. Its distribution of weight also changes and hence the C.G. changes. The pilot must take into account this situation and calculate his "Weight and Balance" not only for the beginning of the flight but also for the end of it.

DEFINITIONS

The **Centre of Gravity** is the point through which the weights of all the various parts of an airplane pass. It is, in effect, the imaginary point from which the airplane could be suspended and remain balanced. The C.G. can move within certain limits without upsetting the balance of the airplane.

The **Balance Datum Line** is a suitable line selected arbitrarily by the manufacturer from which horizontal distances are measured for balance purposes. It may be the nose of the airplane, the firewall or any other convenient point. See Fig. 2.

The **Moment Arm** (D in Fig. 2) is the horizontal distance in inches from the Balance Datum Line to the C.G. (0 in Fig. 2). The distance from the Balance Datum Line to any item, such as a passenger, cargo, fuel tank, etc. is the **arm** of that item (d in Fig. 2).

The **Balance Moment** of the airplane is determined by multiplying the weight of the airplane by the balance moment of the airplane. It is expressed in Inch Pounds. The balance moment of any item is the weight of that item multiplied by its distance from the Balance Datum Line. It is, therefore, obvious that a heavy object loaded in a rearward position will have a much greater balance moment than the same object loaded in a position nearer to the Balance Datum Line.

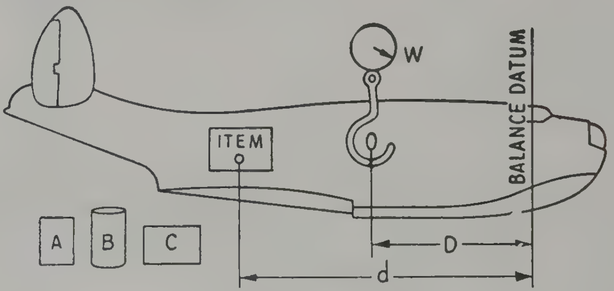


Fig. 2. Balance.

If loads are forward of the Balance Datum their Moment Arms are usually considered negative (−). Loads behind the Datum are considered positive (+)★. The Total Balance Moment is the algebraic sum of the balance moments of the airplane and each item composing the disposable load.

The C.G. is found by dividing the Total Balance Moment (in Inch-Pounds) by the Total Weight (in lb.) and is expressed in inches forward (−) or aft (+) of the Datum Line.

The **Centre of Gravity Range** is usually expressed in inches from the Balance Datum Line (i.e. +39.5" to +45.8"). In some airplanes, it may be expressed as a percentage of the Mean Aerodynamic Chord (40% to 45%). The MAC is the mean chord of the wing.

To calculate the position of the C.G. in percent of MAC: Let us assume that the weight and balance calculations have found the C.G. to be 250" aft of the Balance Datum Line, and the leading edge of the MAC to be 165" aft of the same reference.

★ *In many cases the positive (+) sign is omitted, but the negative (-) sign is always shown. To simplify matters, both are included in our example.*

(Fig. 3). The C.G. will lie, therefore, 85'' aft of the leading edge of the MAC. If the MAC is 200'' in length, the position of the C.G. will be at a position (85 ÷ 200) 42.5% of the MAC. If this calculated C.G. position is within the recommended range (e.g. 40% to 45%), the airplane is properly loaded.

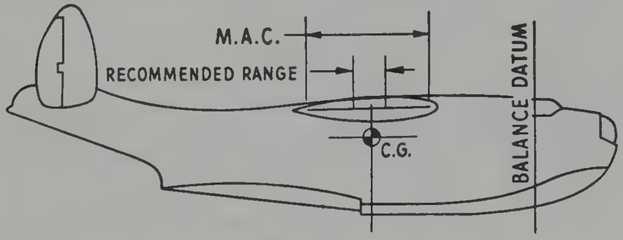


Fig. 3. Mean Aerodynamic Chord.

There are several methods by which weight and balance calculations may be made for any loading situation.

FINDING BALANCE BY COMPUTATION METHOD

For this example, an airplane with a basic weight of 1575 lb. and an authorized gross weight of 2600 lb. has been selected. The Balance Datum Line for the airplane, selected by the manufacturer, is the firewall. The recommended C.G. limits are 35.5'' to 44.8''.

List in a table form the airplane (basic weight), pilot, passengers, fuel, oil, baggage, cargo, etc., their respective weights and arms. Calculate the balance moment of each. Total the weights. Total the balance moments. Divide the Total Balance Moment by the Total Weight to find the Moment Arm (i.e. the position of the C.G.).

Item	Weight Lb.	Moment Arm Inches	Balance Moment Inch-Lb.
Basic Airplane	1575	+36	+56,700
Pilot	165	+37	+ 6,105
Passenger (front seat)	143	+37	+ 5,291
Passenger (rear seat)	165	+72	+11,880
Child (rear seat)	77	+72	+ 5,544
Baggage	90	+98	+ 8,820
Fuel (50 gal.@ 7.2 lb.)	360	+45	+16,200
Oil (2 gal. @ 9 lb.)	18	−15	− 270
	2593		110,270

The Moment Arm for this loading of the airplane is 42.52'' (110,270 ÷ 2593). The total weight (2593 lb.) of the loaded airplane is less than the authorized gross weight (2600 lb.). The Moment Arm falls within the C.G. range (39.5'' to 45.8''). The airplane is, therefore, properly loaded.

The above example examines the situation of an airplane almost at gross weight with the C.G. in a rearward position but within the C.G. range. If this calculation had resulted in a C.G. position that was aft of the C.G. limits, even though the total weight of the airplane was under the authorized gross weight, it would be necessary either to lighten the load or to shift the load by, for example, having the female adult and the male adult passenger change seats.

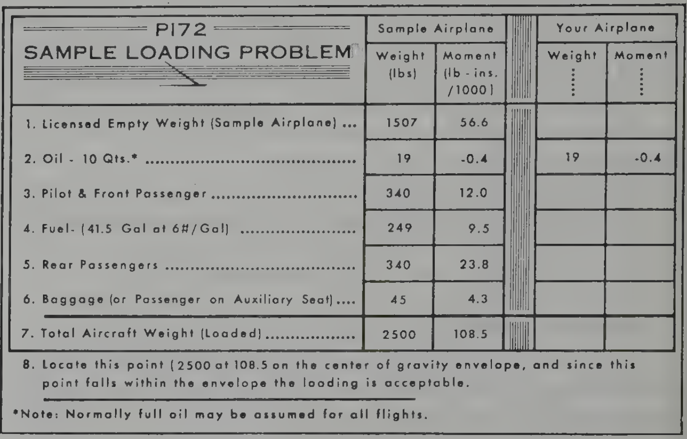
A lightly loaded airplane at the end of a flight when the fuel is almost all consumed may experience the situation that the C.G. moves forward beyond the permissible C.G. range. In some airplanes, when flying with only the pilot on board and no passengers or baggage, it is necessary to carry some suitable type of ballast to compensate for a too far forward C.G. Every pilot should, therefore, calculate the Moment Arm for the lightest possible loading of his airplane to determine if it is acceptable.

FINDING BALANCE BY GRAPH METHOD

Most Airplane Flight Manuals include tables and graphs for calculating weight and balance. The charts in Fig. 4 to 6 are typical of those found in such manuals. They are very easy to use and eliminate the time consuming mathematical steps of the computation method.

Using the charts in Fig. 4, 5 and 6, let us work out a weight and balance problem.

1. Take the licensed Empty Weight and moment/1000 from the Weight and Balance Data Sheet carried in the airplane and enter them in the columns of the chart in Fig. 4. For the airplane used in our problem, these figures are 1507 lbs. and a moment of 56.6.



P172 SAMPLE LOADING PROBLEM	Sample Airplane		Your Airplane	
	Weight (lbs)	Moment (lb - ins. /1000)	Weight	Moment
1. Licensed Empty Weight (Sample Airplane) ...	1507	56.6		
2. Oil - 10 Qts.*	19	-0.4	19	-0.4
3. Pilot & Front Passenger	340	12.0		
4. Fuel- (41.5 Gal at 6#/Gal)	249	9.5		
5. Rear Passengers	340	23.8		
6. Baggage (or Passenger on Auxiliary Seat)....	45	4.3		
7. Total Aircraft Weight (Loaded)	2500	108.5		

8. Locate this point (2500 at 108.5 on the center of gravity envelope, and since this point falls within the envelope the loading is acceptable.

*Note: Normally full oil may be assumed for all flights.

Fig. 4.

2. Enter the weight and moment/1000 for the oil in the proper columns. The sample airplane in this problem uses 10 U.S. quarts (19 lbs. and a moment of −0.4). You usually have a full load of oil for a trip. Therefore these figures can be considered non-variables. (A Canadian or Imperial quart of oil weighs 2¼ lbs.)

3. Compute the weight of the pilot and the front seat passenger. Refer to the Loading Graph (Fig. 5) and find the moment/1000 on the scale. Enter these figures on the chart — 340 lbs. and a moment of 12.0.

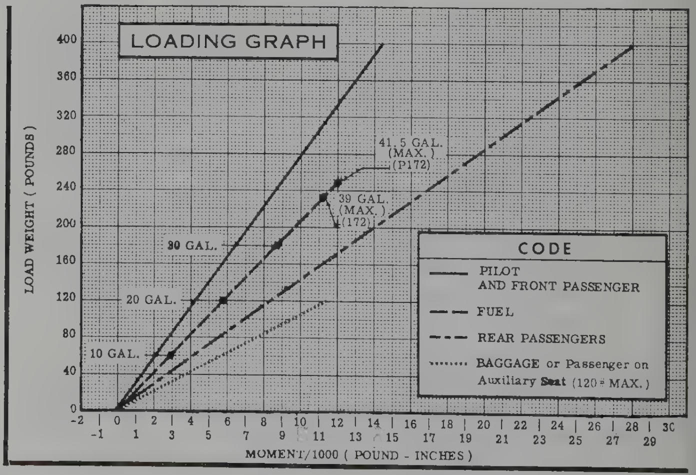


Fig. 5.

4. Determine the weight of fuel on board. (In this case, 41.5 U.S. gallons at 6 lbs. per gallon). Find the moment/1000 from the Loading Graph and enter the figures on the chart — 249 lbs. and a moment of 9.5 (An Imperial gallon of fuel weighs 7.2 lbs.).

5. Calculate the weight of passengers in the rear seat. Using the proper line on the Loading Graph, find the moment/1000 and enter these figures on the chart — 340 lbs. and a moment of 23.8.

6. Weigh the baggage and read the moment/1000 on the proper line on the Loading Graph. Enter these figures on the chart — 45 lbs. and a moment of 4.3.

7. Total the weight column. The total must be less than the gross weight allowed for your airplane. The gross weight of the

airplane used in this problem is 2500 lbs. If the total in the weight column exceeds the gross weight, you must lighten the airplane's load.

Total the moment column. Remember to subtract the oil moment.

8. Refer to the Centre of Gravity Moment Envelope (Fig. 6). Locate the intersection of the lines connecting the total weight with the total moment/1000. If this point is within the envelope,, your airplane is loaded within proper limits. If this point of intersection is outside the envelope, the load must be adjusted.

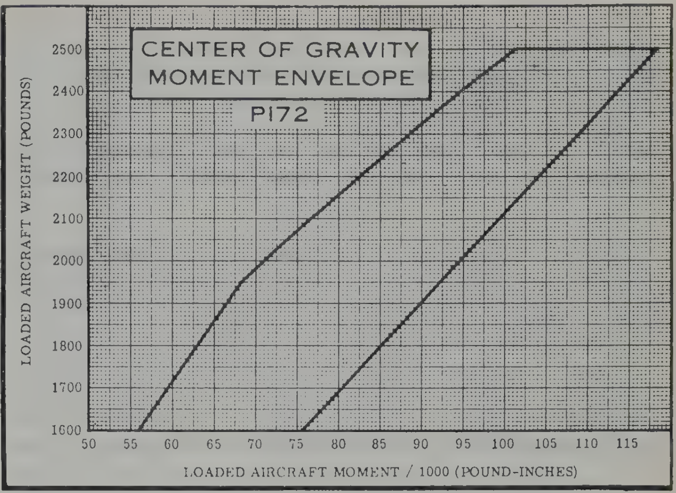


Fig. 6.

AIRPLANE PERFORMANCE

EFFECT OF TEMPERATURE AND ALTITUDE ON AIRPLANE PERFORMANCE

The figures published in the Flight Manual for the performance capabilities of a certain model of airplane are always related to standard atmosphere. However, only rarely will the airplane actually operate under conditions that approximate standard atmosphere.

Air density decreases with altitude. At 10,000 feet, the pressure exerted by a column of air is considerably less than at sea level. As a result, at high elevation airports, an airplane requires more runway to take-off. Its rate of climb will be less, its approach will be faster (because the TAS will be faster than the IAS) and the landing roll will be longer.

Air density also decreases with temperature. Warm air is less dense than cold air because there are fewer air molecules in a given volume of warm air than in the same volume of cooler air. As a result, on a hot day, an airplane will require more runway to take-off, will have a poor rate of climb and a faster approach and will experience a longer landing roll.

In combination, high and hot, a situation exists that can well be disastrous for an unsuspecting, or more accurately, an uninformed pilot. The combination of high temperature and high elevation produces a situation that aerodynamically reduces drastically the performance of the airplane. The horsepower output of the engine is decreased because its fuel-air mixture is reduced. The propeller develops less thrust because the blades, as airfoils, are less efficient in the thin air. The wings develop less lift because the thin air exerts less force on the airfoils. As a result, the take-off distance is substantially increased, climb performance is substantially reduced and may, in extreme situations, be non-existent.

Fig. 7 illustrates the effect of **Density Altitude.** The take-off run at sea level with a temperature of 15°C (standard air) is 1000 feet. At a 5000 foot elevation, with a temperature of 20°C, the take-off run is doubled and the rate of climb diminishes 55%.

DENSITY ALTITUDE KOCH CHART

When taking off at high altitude, or with higher than normal temperature (or both) the **Koch Chart**, Fig. 8, may be used to estimate the increase in an airplane's take-off roll, and the

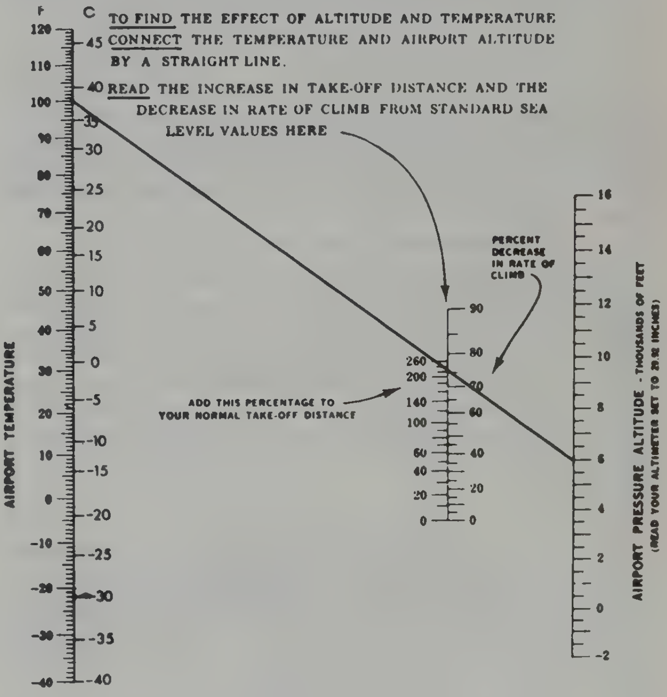


Fig. 8. Koch Chart.

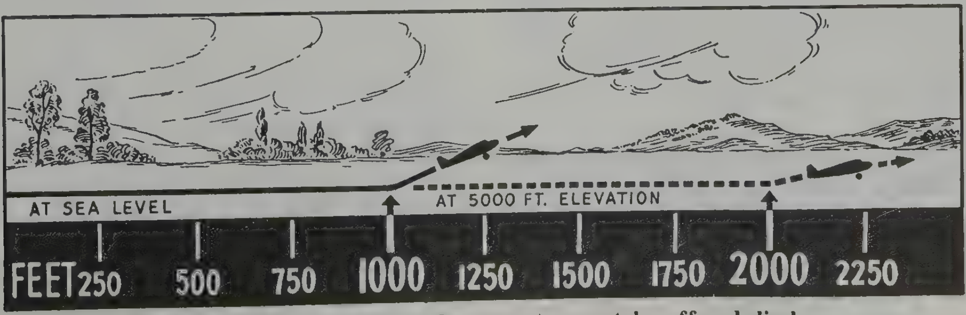


Fig. 7. Effect of altitude and temperature on take-off and climb.

decrease in its rate-of-climb over its known standard-air, sea-level values. For example, assume a Pressure Altitude of 6000 feet and an airport temperature of 37°C. Locate 6000 feet on the Airport Pressure Altitude Index on the right edge of the chart. Locate 37°C on the Temperature Index on the left edge of the chart. Join these two points and note where the line cuts the Percentage Index. The airplane's normal take-off distance would be lengthened by 230% and its initial rate of climb would fall off 76%.

Density Altitude can be calculated for any given combination of Pressure Altitude and temperature on the Circular Slide Rule portion of a Flight Computer. The procedure for doing so has already been discussed in the Chapter **Navigation.**

If you do not have a Koch Chart, take-off performance can be calculated by a relatively simple rule of thumb. Remember, first, than an **increase** in Density Altitude will cause a corresponding **decrease** in take-off performance. Add 10% to the normal take-off run for every 1000 foot increase in the Density Altitude.

For example: At an airport at sea level, the altimeter setting is 29.92" and the altimeter indicates that the Pressure Altitude is 0 feet. The temperature is 15°C which is Standard Air. The take-off run under these conditions would be 1000 feet. Suppose that the temperature were to rise to 23°C and the Pressure Altitude remain constant. The Density Altitude of the airport at sea level would now be 1000 feet. For the increase of 1000 feet in Density Altitude, add 10% to the take-off run which would now be 1100 feet.

TAKE OFF PERFORMANCE CHARTS

The Airplane Flight Manual publishes information, usually in chart form, on the take-off performance of a specific model of airplane. A pilot should familiarize himself with these charts to be able to predict how his airplane will perform under varying conditions and should refer to these charts whenever there is any doubt that the take-off conditions may not be sufficient for the performance capabilities of the airplane. In addition, it is important to remember that the performance data is derived from tests on a "clean" new airplane. Any typical general aviation airplane, a year or more old, will have a poorer performance potential than that predicted by the charts.

Fig. 9 depicts a Take-Off Data Chart which tabulates the expected ground run and the expected distance over the ground needed to clear a 50 foot obstacle. The figures are given for a gross weight of 2350 lb. and for lighter loadings of 2000 lb. and 1700 lb. Comparison figures are also given for a still wind condition and for headwinds of 15 mph and 30 mph. The table includes take-off performance at sea level, and at elevations of 2500 feet, 5000 feet and 7500 feet. The chart assumes standard air conditions.

TAKE-OFF DATA

TAKE-OFF DISTANCE FROM HARD SURFACE RUNWAY WITH FLAPS 1/4

GROSS WEIGHT POUNDS	IAS AT 50' MPH	HEAD WIND KNOTS	AT SEA LEVEL & 59°F		AT 2500 FT. & 50°F		AT 5000 FT. & 41°F		AT 7500 FT. & 32°F	
			GROUND RUN	TOTAL TO CLEAR 50 FT OBS	GROUND RUN	TOTAL TO CLEAR 50 FT OBS	GROUND RUN	TOTAL TO CLEAR 50 FT OBS	GROUND RUN	TOTAL TO CLEAR 50 FT OBS
2350	67	0	845	1575	1025	2000	1260	2740	1575	4680
		10	585	1190	720	1530	900	2145	1140	3765
		20	370	850	465	1115	595	1600	770	2915
2000	62	0	580	1060	695	1280	850	1610	1050	2150
		10	385	775	475	955	585	1215	740	1650
		20	230	530	290	665	370	865	475	1205
1700	57	0	400	745	475	885	580	1070	710	1340
		10	255	535	315	640	385	785	485	1000
		20	145	350	180	430	230	535	295	695

NOTES: 1. Increase distance 10% for each 20°F above standard temperature for particular altitude.
2. For operation on a dry, grass runway, increase distances (both "ground run" and "total to clear 50 ft. obstacle") by 7% of the "total to clear 50 ft. obstacle" figure.

Fig. 9. Take-Off Data Chart.

The performance figures in Fig. 9 are given for take-off from a hard surface runway. For operation on a dry, grass runway, the distance for both take-off and to clear a 50 foot obstacle should be increased by 7%. Less favourable conditions such as long grass, sand, mud, glassy water (in the case of seaplanes) and soft snow (in the case of skiplanes) can easily double the take-off run and, in some cases, make take-off impossible.

To determine the expected performance of the airplane to which the table in Fig. 9 applies at an airport with an elevation of 4000 feet, it would be necessary to interpolate a figure by comparing the stated performance at 2500 feet and at 5000 feet. It would appear that for every 500 feet of additional elevation, the take-off run increases by [(895 − 745) ÷ 5] 30 feet. Therefore, the take-off run at 4000 feet elevation would be 835 feet [745 + (30 × 3)].

For some airplanes, the take-off data is given only for gross weight. A useful rule of thumb to remember is: A 10% reduction in weight will result in a 20% reduction in take-off roll. (The reduction in take-off distance is double the percentage decrease in weight and vice versa if weight is added.)

Some Airplane Flight Manuals publish a graph that relates take-off distance to Density Altitude. Fig. 10 illustrates such a graph. To use this graph, the pilot must first calculate the Density Altitude of his airport of operation.

For example, let us assume that the Density Altitude is 5000 feet. Locate the figure 5000 on the left edge of the graph. Locate the intersection of the 5000 foot line with the "ground run" line and the "over 50 ft. barrier" line. The ground run to achieve take-off will be approximately 1000 feet and the distance required to clear a 50 foot obstacle will be approximately 2335 feet.

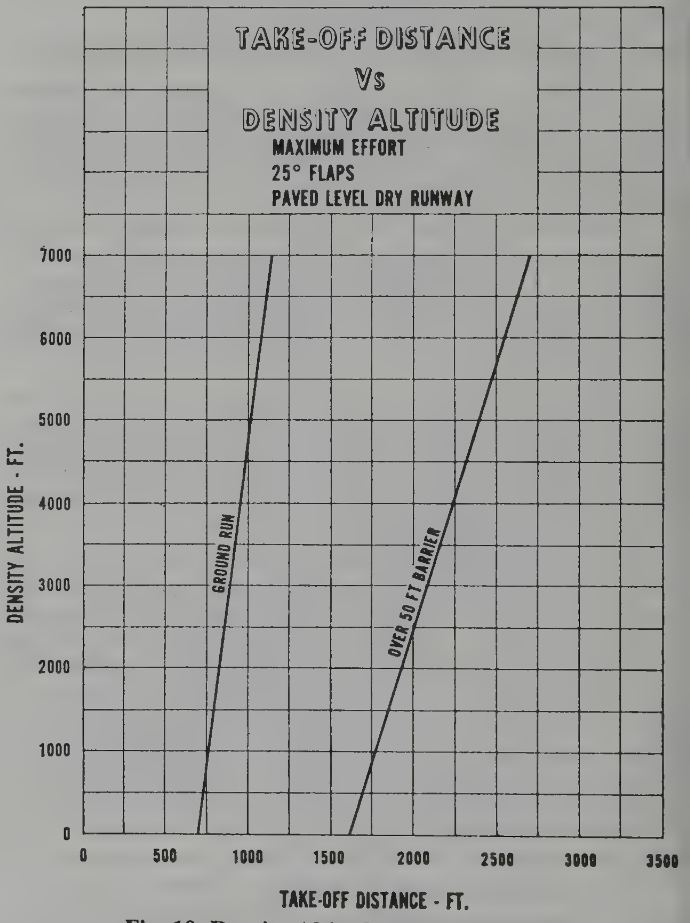


Fig. 10. Density Altitude Take Off Graph.

If after calculating Density Altitude and checking the tables, it appears that the take-off run will require more runway than is available, a pilot has several alternatives. He can lighten the load, if possible, or he can wait until the temperature decreases. Generally the most critical time for flight operations at high elevation airports on hot days is from mid-morning through mid-afternoon. Airplane operations should, therefore, be planned for early morning and late evening hours.

It is important to remember that in taking off from airfields that are at high elevation, the pilot should use as a reference the same Indicated Airspeed that he would use during take-off from an airfield at sea level. It is the True Airspeed that is affected by the increase in elevation and temperature.

CLIMB PERFORMANCE CHARTS

The Airplane Flight Manual also publishes data for climb performance. Fig. 11 illustrates a typical table of figures for Maximum Rate of Climb. The Maximum, or Best Rate of Climb, it will be remembered, is the rate of climb which will gain the most altitude in the least time and is used to climb after take off until ready to leave the traffic circuit. The table in Fig. 11 lists the rate of climb in feet per minute for various weights and at various altitudes. Note how the rate of climb decreases with altitude. At gross weight, at sea level, the rate of climb is 670 ft/min, at 10,000 feet 225 ft/min, at 15,000 feet 0 ft/min. At 15,000 feet, therefore, the airplane has reached its service ceiling.

These climb performance figures are calculated with flaps up, full throttle and the mixture leaned for maximum rpm above 5000 feet. They are also calculated at standard air conditions.

MAXIMUM RATE-OF-CLIMB DATA

GROSS WEIGHT POUNDS	AT SEA LEVEL & 59°F			AT 5000 FT & 41°F			AT 10,000 FT & 23°F			AT 15,000 FT & 5°F		
	IAS MPH	RATE OF CLIMB FT/MIN	GAL. OF FUEL USED	IAS MPH	RATE OF CLIMB FT/MIN	FROM S.L. FUEL USED	IAS MPH	RATE OF CLIMB FT/MIN	FROM S.L. FUEL USED	IAS MPH	RATE OF CLIMB FT/MIN	FROM S.L. FUEL USED
2350	88	670	1.0	87	445	2.9	85	225	5.3	84	0	---
2000	86	825	1.0	85	585	2.5	83	350	4.1	82	110	7.1
1700	84	960	1.0	83	710	2.2	81	460	3.5	80	210	5.5

NOTES:
1. Flaps up, full throttle and mixture leaned for smooth operation above 5000 ft.
2. Fuel used includes warm up and take-off allowance.
3. For hot weather, decrease rate of climb 20 ft./min. for each 10°F above standard day temperature for particular altitude.

Fig. 11. Maximum Rate of Climb Data Chart.

Some Airplane Manuals also publish a graph that relates climb performance to Density Altitude. The graph in Fig. 12 is such a chart. It indicates the climb performance that can be expected at varying Density Altitudes. At a Density Altitude of 10,000 feet, for example, the airplane for which this chart is applicable will climb at about 250 feet per minute. At a Density Altitude of 16,000 feet, it has reached its ceiling and will not climb any higher.

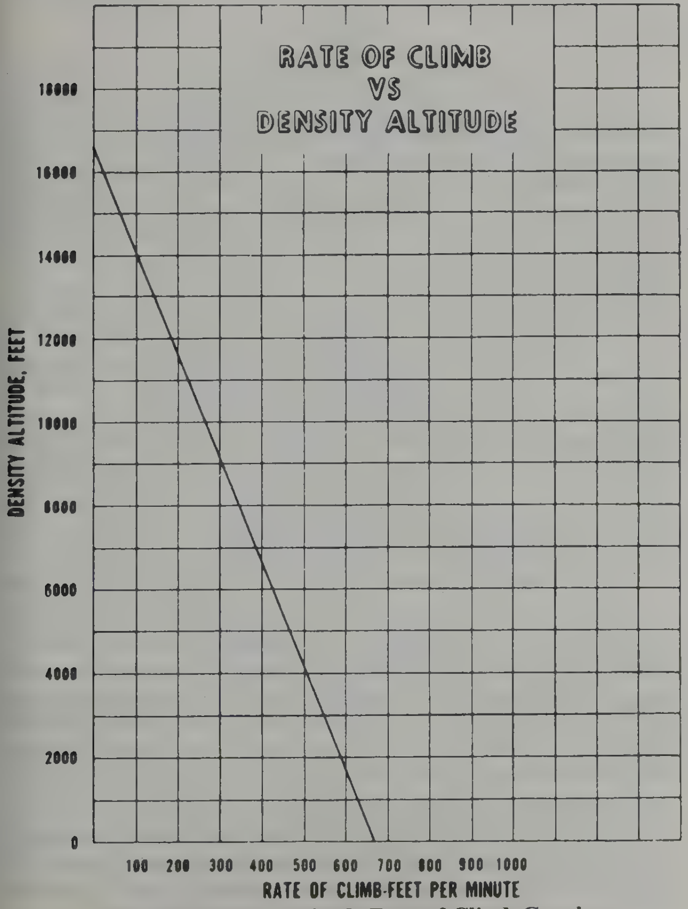


Fig. 12. Density Altitude Rate of Climb Graph.

Many Airplane Manuals also publish charts for Cruise Climb (Fig. 13). Cruise Climb, or Normal Climb, is the climb airspeed used for a prolonged climb. The chart indicates the fuel used, time required to reach altitude, and "still air" distance covered in order to reach various altitudes when climbing at a certain indicated airspeed with various power settings.

CRUISE CLIMB

POWER SETTING		Climb IAS MPH	Fuel Flow Gal. Hr Per Eng	5000 FT. 41°F FROM SEA LEVEL			10000 FT. 23°F FROM SEA LEVEL			15000 FT. 5°F FROM SEA LEVEL		
RPM	M.P.			Dist. Miles	Time Min.	Fuel Used Gal.	Dist. Miles	Time Min.	Fuel Used Gal.	Dist. Miles	Time Min.	Fuel Used Gal.
2600	F.T.	150	Full Rich	9	3	7	18	7	10	30	11	13
2450	29	130	15.5	10	5	7	22	10	9	36	15	12
2450	29	150	15.5	15	6	7	32	12	10	52	13	13
2300	28	150	12.6	20	8	7	43	16	11	70	25	14

NOTE: WARM-UP AND TAKE-OFF ALLOWANCE 4 GALLONS AT SEA LEVEL. MIXTURE AT RECOMMENDED FUEL FLOW, FLAPS AND GEAR UP.

Fig. 13.

CRUISE PERFORMANCE CHARTS.

Performance figures for cruise at gross weight are also given in most Airplane Flight Manuals. These charts show the fuel consumption, true airspeed, endurance and range that may be expected **when cruising** at a certain altitude with the engine being operated at normal lean mixture, at various combinations of rpm and MP settings (to give a required % of power).

The figures in the chart in Fig. 14 are for a typical general aviation airplane. They are tabulated for cruise at various altitudes. 2500 feet and 5000 feet are illustrated. The Manual includes figures for 7500 feet, 10,000 feet, etc. up to the airplane's service ceiling.

CRUISE PERFORMANCE

LEAN MIXTURE

Standard Conditions ↘ Zero Wind ↘ Gross Weight- 2800 Pounds

RPM	MP	% BHP	GAL/ HOUR	TAS MPH	60 GAL (NO RESERVE) ENDR. HOURS	60 GAL (NO RESERVE) RANGE MILES	79 GAL (NO RESERVE) ENDR. HOURS	79 GAL (NO RESERVE) RANGE MILES
2500 FEET								
2450	23	76	14.2	158	4.2	670	5.6	885
	22	72	13.4	154	4.5	690	5.9	910
	21	68	12.7	151	4.7	715	6.2	940
	20	63	12.0	148	5.0	730	6.6	965
2300	23	71	13.1	154	4.6	700	6.0	925
	22	67	12.2	149	4.9	740	6.5	970
	21	62	11.5	145	5.2	760	6.9	1005
	20	59	11.0	142	5.5	775	7.2	1020
2200	23	67	12.1	149	5.0	745	6.5	980
	22	63	11.4	146	5.3	770	6.9	1010
	21	59	10.8	142	5.6	790	7.3	1040
	20	55	10.2	138	5.9	810	7.7	1065
2000 MAXIMUM RANGE SETTINGS	20	47	8.7	126	6.9	865	9.1	1135
	19	43	8.2	121	7.3	890	9.6	1170
	18	39	7.5	113	8.0	900	10.5	1185
	17	35	7.0	105	8.6	905	11.3	1190
5000 FEET								
2450	23	78	14.5	163	4.1	670	5.4	885
	22	73	13.6	159	4.4	700	5.8	925
	21	70	13.0	156	4.6	720	6.1	950
	20	65	12.2	151	4.9	750	6.5	985
2300	23	73	13.4	158	4.5	710	5.9	930
	22	69	12.6	155	4.7	730	6.3	965
	21	64	11.9	151	5.0	760	6.6	1005
	20	60	11.2	146	5.4	785	7.1	1035
2200	23	68	12.4	155	4.8	750	6.4	985
	22	64	11.7	151	5.1	775	6.8	1020
	21	60	11.0	146	5.5	800	7.2	1050
	20	57	10.5	143	5.7	815	7.5	1075
2000 MAXIMUM RANGE SETTINGS	19	45	8.5	126	7.1	895	9.3	1175
	18	41	7.9	118	7.6	905	10.0	1190
	17	37	7.3	111	8.2	910	10.8	1200
	16	34	6.8	103	8.8	905	11.6	1190

Fig. 14. Cruise Performance Chart.

It must be noted, however, that these figures are calculated on standard air conditions and zero wind. Wind direction and velocity will not affect fuel consumption or endurance but will certainly affect range. Interpolation of the figures must also be made for variations as a result of Density Altitude.

Some Manuals publish their cruise performance data in graph form such as that shown in Fig. 15. By reference to the graph, a pilot can determine the expected range for any combination of Density Altitude and percentage of power. For example, at 5000 feet Density Altitude and 65% power, the airplane for which this graph applies, has a range of approximately 1050 miles.

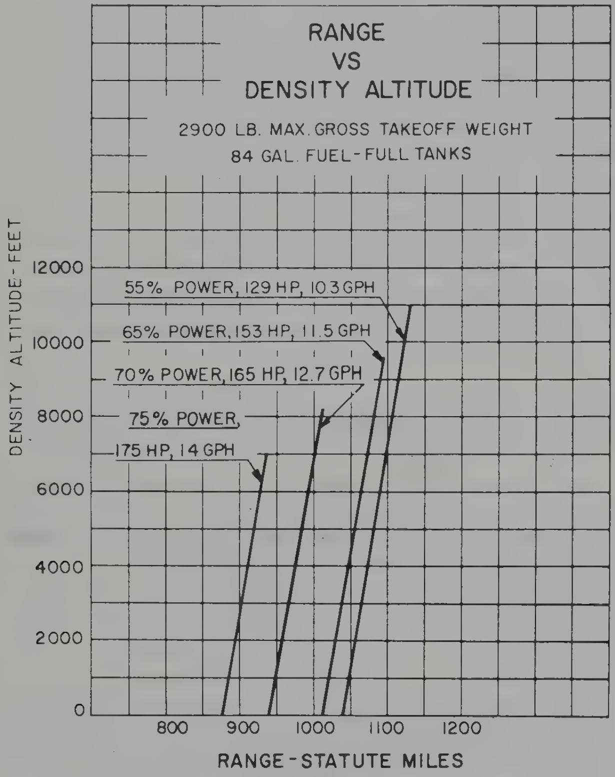


Fig. 15. Cruise Performance Graph.

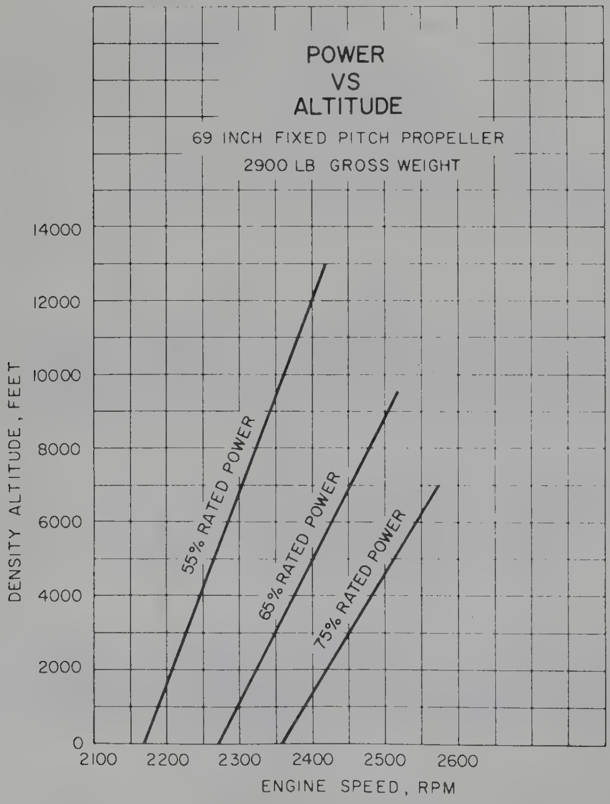


Fig. 16. Power Graph.

To use the graph in Fig. 15, the pilot must also refer to a graph (Fig. 16) relating power to altitude to determine what rpm will give the percentage of power he requires. For example, to achieve 65% power at 5000 feet Density Altitude, it is necessary to operate at a power setting of 2400 rpm.

LANDING PERFORMANCE CHARTS

Perfect landings are usually preceded by deliberately planned and well executed approaches. Correct approach speeds are important. The Airplane Flight Manual for any particular model of airplane recommends the speeds to use on approach with various flap settings. These airspeeds should always be used.

If information on approach speeds is not available, a useful rule of thumb to determine final approach speed for the average conventional design airplane may be found by applying the formula presented in Fig. 17.

UNDER NORMAL C.G. AND LOAD CONDITIONS

FINAL APPROACH SPEED = 1.3 V_{SO} *

POWER-OFF STALL I.A.S.	OVER THE FENCE I.A.S.
40	52
45	59
50	65
55	72
60	78
65	85
70	91
75	98
80	104
85	111
90	117
95	124
100	130

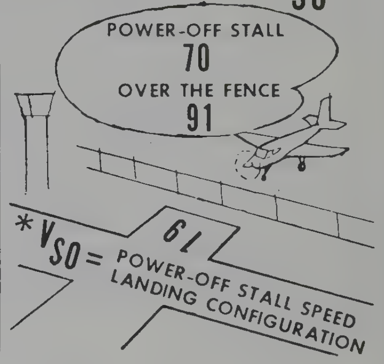


Fig. 17.

Most Airplane Flight Manuals publish information on landing performance in a table such as that in Fig. 18. The table assumes full flaps, power on and no wind and lists the expected ground roll and distance to clear a 50 foot obstacle when landing at airports of varying elevations. A recommended 10% reduction in landing distance is indicated for every 4 knots of headwind. If, for example, the velocity of the wind down the runway at an airport at 2500 feet is 8 knots, the ground roll can be expected to be 336 feet [420 − (420 × 20%)].

LANDING DISTANCE TABLE

LANDING DISTANCE WITH FULL FLAPS, POWER OFF, AND NO WIND ON HARD SURFACE RUNWAY

		AT SEA LEVEL & 59°F		AT 2500 FT. & 50°F		AT 5000 FT. & 41°F		AT 7500 FT. & 32°F	
GROSS WEIGHT POUNDS	IAS AT 50' MPH	GROUND ROLL	TOTAL TO CLEAR 50 FT. OBS.	GROUND ROLL	TOTAL TO CLEAR 50 FT. OBS.	GROUND ROLL	TOTAL TO CLEAR 50 FT. OBS.	GROUND ROLL	TOTAL TO CLEAR 50 FT. OBS.
2350	66	400	1135	420	1195	445	1265	470	1335

NOTES:
1. Reduce landing distance 10% for each 4 knots of headwind.
2. For operation on a dry, grass runway, increase distances (both "ground roll" and "total to clear 50 ft. obstacle") by 20% of the "total to clear 50 ft. obstacle" figure.

Fig. 18. Landing Distance Table.

Density Altitude affects the landing performance of an airplane as greatly as it affects take-off performance. High temperature and high elevation will cause an increase in the landing roll because the True Airspeed is higher than the Indicated Airspeed. Therefore, even though using the same Indicated Airspeed for approach and landing that is appropriate for sea level operations, the True Airspeed is faster, resulting in a faster groundspeed (with a given wind condition). The increase in groundspeed naturally makes the landing distance longer and should be carefully considered when landing at a high elevation field, particularly if the field is short.

Most Airplane Flight Manuals contain performance charts and tables such as the one in Fig. 19 which relates landing distance to Density Altitude. Pilots should develop the habit of referring to these charts in order to anticipate the distance that will be required to land their airplane under various conditions of flight.

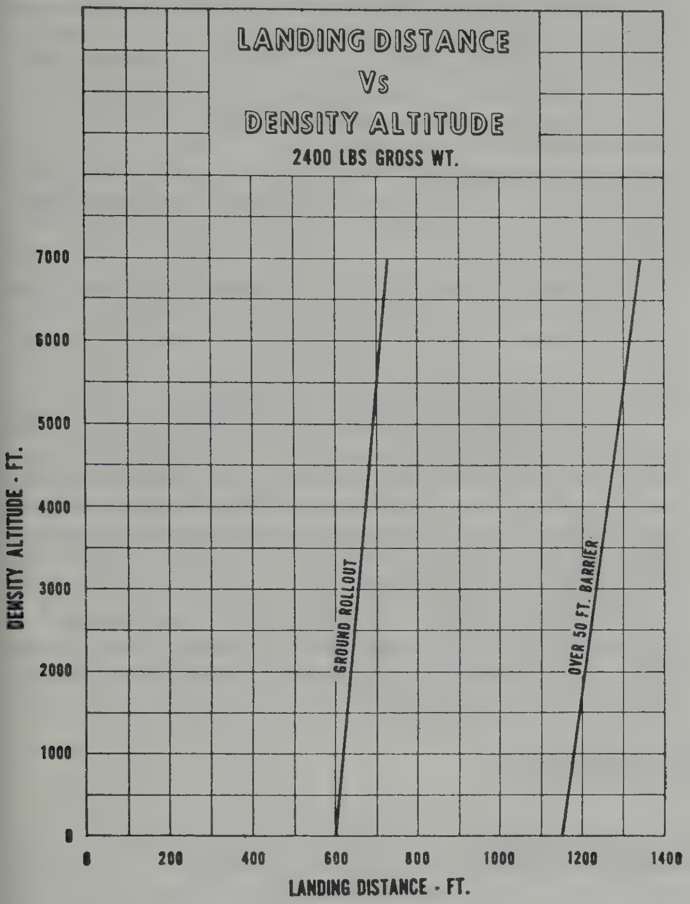


Fig. 19.

CROSS WIND LANDINGS AND TAKE OFFS

Any pilot who has attempted to land a light airplane at a small airport with a single strip that happened that day to be directly 90° to a heavy wind knows the value of good cross wind technique.

There are essentially two kinds of contrary wind conditions that affect light planes on landing. There is the fairly steady wind at a pronounced angle to the runway which can be determined. There is also the gusty changeable wind. This second cross wind condition requires instinctively correct responses from the pilot, who must use aileron for keeping his airplane over the runway and opposite rudder to line it up with the runway, and at the same time be prepared to deal with sudden changes in airspeed and altitude due to the gusty conditons.

When the wind is gusting, a shift in almost any direction, even to 180°, can occur. The pilot is well advised to pay special attention to the behaviour of trees, bushes and dust and not just the windsock.

How much contrary wind can an airplane handle? This information is usually given in the Owner's Manual. If the manual has been conscientiously written, it will list windspeed maximums for every conceivable angle. It may, however, give only the maximum crosswind angle and the maximum wind velocity.

A cross wind component chart (Fig. 20) can be used to determine the maximum permissible windspeeds for varying cross winds. All airplanes of North American manufacture are designed to handle cross winds of 90° with a velocity of 20% of their stall speed. An airplane with a stall speed of 60 mph, for example, can tolerate a 90° cross wind of 12 mph. (60 × 20%). Draw a line on the graph parallel to the landing path from the point 12 mph on the index at the bottom of the chart. The point at which this line intersects each of the "Wind Degrees off Runway" lines and the Speed Curves indicates the permissible wind speeds for the varying cross wind conditions. For a cross wind of 60 degrees off the runway, the maximum permissible wind speed is 14 mph; at 30 degrees, 24 mph; at 15 degrees, 45 mph.

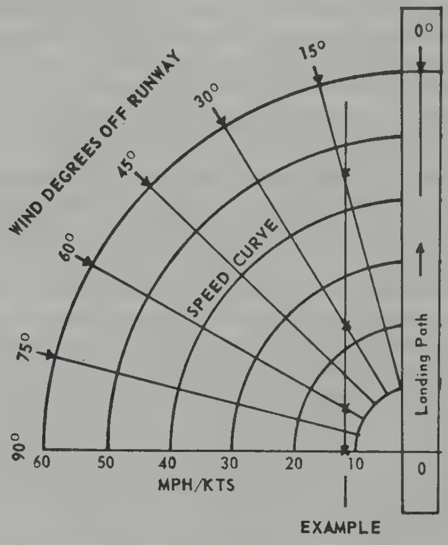


Fig. 20. Cross Wind Component Chart.

Cross wind considerations are of considerable importance for take-off as well as for landing. In take-off the effect of torque must be remembered. Since torque will tend to push the airplane's nose to the left, a cross wind from the right will not be too difficult to handle. In a cross wind from the left, however, it could be possible to run out of right rudder. If the cross wind component is near marginal, a left-hand cross wind calls for a "stay at home" decision, unless the airplane has counter-rotating propellers.

In a stiff cross wind with full upwind aileron held, it is possible to end up making the final segment of the take-off on the upwind wheel only. This makes the airplane difficult to handle but the pilot should avoid the temptation to haul the airplane off prematurely. It is advisable to break ground at a slightly higher than normal speed, even if it is necessary to force the airplane to remain on the runway. Once in the air, the pilot wants to have the positive control responses that come with good flying speed.

On the other hand, it is inadvisable to carry too much airspeed when landing in a cross wind. The greater the angle of the cross wind, the less head wind component there is, so that in a 90° cross wind there is no head wind component at all. Although in extremely gusty conditions, some extra speed is advisable, too much may complicate the job of bringing the airplane to a stop before the end of the runway.

CRUISING SPEEDS

Between an airplane's top speed and its stalling speed, there is a wide range of speeds that have often been referred to as the "working speeds". Each is the answer to a particular problem of practical flying.

Best Gliding Speed or Normal Glide. The speed at which an airplane with power off will glide the farthest distance. This is the speed at which the lift/drag ratio is best and therefore might be called the "Speed of Least Drag".

Speed of Slowest Descent. The speed at which the airplane loses altitude at the least rate. In a nose high attitude, near the stalling speed, the airplane sinks most slowly. This speed is made constant use of by glider pilots.

Maximum Range Speed. The speed at which the airplane travels the most miles per gallon of fuel. This speed is about 5 to 10% faster than the Best Gliding Speed.

Maximum Endurance Speed. The speed at which the fuel consumption is the least per hour. To achieve this condition of flight, the airplane is flown quite slowly, with minimum power, very nose-high, with the wings at a high angle of attack. The airplane is not covering much distance for it is too slow but its endurance is substantially extended.

Maneuvring Speed. The maximum speed at which the airplane should be flown in rough air. It is the speed least likely to permit structural damage to the airplane in rough air or during acrobatic maneuvres. Maneuvring speed for most airplanes is set at twice the normal straight flight stalling speed.

Optimum Cruise Speed. The speed at which the best balance between use of fuel and maximum range is achieved.

Best Rate of Climb Speed. The speed at which the airplane will gain the most altitude in the least time. This speed is rather fast; for most airplanes it is approximately the same speed as that of Best Glide.

Best Angle of Climb Speed. The speed at which the airplane climbs most steeply, gaining the most altitude for distance covered over the ground. In routine flying, it is seldom necessary to use Best Angle of Climb Speed but it is of importance when it is necessary to climb out over a high obstacle at the end of a runway. It is, however, not a climbing procedure that should be used except in emergency. Firstly, it is a speed that is not much above the stall and the pilot must be very vigilant that he does not permit the airplane to stall. Secondly, at such a slow speed, with full power, insufficient air is passing over the engine to cool it properly. The engine is therefore likely to overheat and the resulting engine wear is undesirable.

Air Endurance. The maximum **time** an airplane can continue to fly under given conditions ★ with a given quantity of fuel.

Range. The maximum **distance** an airplane can fly under given conditions ★ with a given quantity of fuel.

★ **Given Conditions.** Both airspeed and altitude effect the range and endurance. The best airspeed for maximum *endurance* is generally **less** than that for maximum *range.* Generally speaking, a propeller driven airplane may be flown at a relatively low altitude for maximum endurance. For maximum range, a propeller driven airplane should be flown at that height at which, at full throttle, the Indicated Airspeed is about 5 to 10% better than the Best Glide Speed. This is realized at a relatively high altitude. A jet, on the other hand, would fly at high altitude for both range and endurance.

Range and endurance, when stated in an airplane specification, are usually based on still air, standard atmosphere conditions. However, they may be computed for any assumed wind direction and wind speed.

Airplane performance is always a compromise between such variable factors as range vs payload, endurance vs airspeed, etc.

USE OF PERFORMANCE CHARTS

The performance information that is available to a pilot in the form of the tables and graphs that have been illustrated in the preceding sections is very valuable. A pilot should, therefore, thoroughly familiarize himself with them and should practise using them at every opportunity in order to gain confidence in their use and to determine for himself that his calculated or anticipated performance equals the actual or realized performance on any particular flight.

The charts are particularly useful in planning a cross country flight and in solving the navigational problems of range, fuel consumption, etc. that are part of proper pre-flight planning.

WAKE TURBULENCE

The theory of wing tip vortices was introduced in the Chapter **Theory of Flight** in the discussion of induced drag. As the lift producing airfoil passes through the air, the air rolls up and back about each wing tip producing two distinct counter rotating vortices, one trailing each wing tip. (Fig. 21.) The intensity of the turbulence within these vortices is directly proportional to the weight and inversely proportional to the wing span and the speed of the airplane. The heavier and slower the airplane, therefore, the greater is the intensity of the air circulation in the vortex cores. The most violent vortices would therefore be generated by airplanes during take-off and landing and at near gross weights.

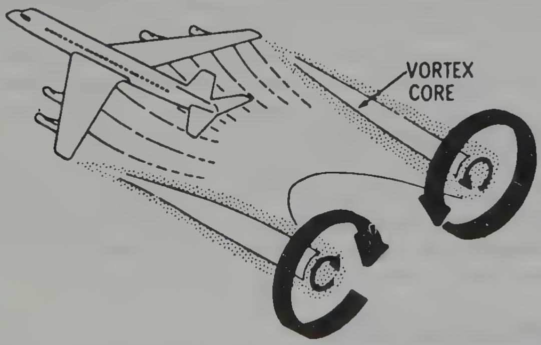


Fig. 21.

Similar vortices are generated by rotary wing aircraft. These vortices have the same internal air circulation as those generated by fixed wing airplanes, but are potentially more dangerous because of the helicopter's lower operating speeds.

The vertical gusts encountered when crossing laterally through the vortex can impose structural loads as high as 10 g's on a small airplane flying at a high angle of attack. The combined effect of an upgust immediately followed by a down-gust has been estimated as high as 80-feet-per-second. Most small planes are designed to withstand vertical gusts of 30-feet-per-second at their normal operating speeds.

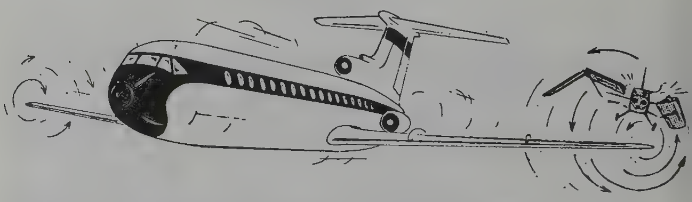


Fig. 22. Hazards of Wing Tip Vortex.

There is a distinct possibility of structural failure when an airplane crosses a pair of vortices at large angle (about 90°). The severe up-down-down-up forces and the pilot's attempt to counteract them could result in airframe design limits being exceeded. Loss of control is another result of encountering these unseen monsters. Vortex cores can produce a roll rate of 80 degrees per second, a situation with which the small light airplane is structurally unable to cope.

Vortex generation starts with lift-off and ends when the aircraft touches down. The vortices settle below and behind the aircraft but tend to level off about 1000 feet below the aircraft's flight path. They may trail the generating aircraft by 10 miles and, in still air, decay slowly. Wake turbulence may be encountered as long as 5 minutes after the passage of the generating aircraft. Atmospheric turbulence does, however, help break up the turbulence more quickly.

When the vortices sink to the ground, they tend to move laterally outward over the ground at a speed of about 5 knots. This characteristic means that the laterally moving vortices may position themselves over a parallel runway and constitute a hazard to airplanes operating there. In a crosswind condition, the lateral movement of the upwind vortex will be decreased while the movement of the downwind vortex will be increased. As a result, the upwind vortex may remain stationary in the touchdown zone.

The advent of the huge jumbo jets, in the class of the 747 and C-5, makes the problem of wake turbulence even more acute. These aircraft generate roll velocities exceeding the roll control capability of some of the larger light airplanes and far in excess of the capability of small airplanes.

The phenomenon of wake turbulence is of immense importance to a pilot. In fact, it can be a matter of life and death. It is of prime importance, therefore, that a pilot, for his own safety, learn to envision the location of the vortex wake generated by large aircraft so that he can avoid encountering the very serious hazards that are associated with this situation.

WAKE TURBULENCE AVOIDANCE

Remember that the vortices, in still air, have a downward and outward movement but that the ambient wind will alter their normal pattern of movement.

During flight. Avoid crossing behind and below the flightpath of a large, heavy airplane or of a helicopter. Alter course, or climb to be above the expected wake turbulence.

During take-off. On the same or a parallel runway. Start the take-off roll at the end of the runway and plan to be airborne prior to the point where the previous aircraft's take-off was made. A normal climb should keep you above the descending vortices of the preceding aircraft.

Do not make intersection take-offs when large aircraft are using the same runway.

On an intersecting runway. Plan to be airborne before you cross the intersection, remembering to keep your flight path well above that of the aircraft that departed on the other runway.

When following an aircraft that has just landed, plan to become airborne beyond the point of touchdown of the preceding aircraft.

During landing. When following a heavy aircraft that has just taken off, plan to touch down before the point where the preceding aircraft took off.

When following an aircraft that has just landed, plan to touch down beyond the point where the preceding aircraft touched down, remembering to keep your approach path above that of that aircraft.

When the tower controller advises, **"Caution Wake Turbulence,"** he is following procedures and warning you of the possible existence of this phenomenon. It is, however, solely the pilot's responsiblity to avoid encountering it. Don't hesitate to ask for further information if you believe it will assist you in analysing the situation and deciding on a course of action. Even though you have received a clearance to land or take-off, if you believe it safer to wait, or to use a different runway, or in some other way to alter your operation, ask the controller for a revised clearance. The controller is interested in the prevention of accidents too and will assist you in any way he can while accomplishing his job of expediting traffic.

RULES OF THE AIR

Air Regulations are undergoing constant change and revision. To date, no attempt has been made to establish an internationally uniform code. For these reasons, only a limited amount of information regarding Air Regulations will be found in this manual. However a knowledge of the current Air Regulations of the country or countries in which he may be flying is the most important of all the knowledge which a pilot must have in his possession.

Indeed, it is the responsibility of the pilot to make himself familiar with, and conform to, all regulations and requirements which pertain to the airplane he flies and the conditions under which it is being flown.

The government published Air Regulations and Air Navigation Orders and the revisions to this legislation that are regularly distributed to all licensed pilots should be required reading. Information Circulars and NOTAMS are also distributed to all pilots and should be carefully scrutinized. Information Circulars cover practically every subject to do with aviation in Canada. They are informative in nature, although some may be mandatory. NOTAMS deal mostly with matters of an urgent nature, such as danger and restricted areas, obstructions, airport construction, changes in navigation and control procedures.

The Flight Information Manual is especially useful for it is updated and published on a regular basis and incorporates Air Regulations and ANOs and other aeronautical information that is pertinent to the basic requirements to fly VFR within Canadian airspace.

CERTIFICATE OF AIRWORTHINESS

No airplane may be flown unless it is registered and has a Flight Permit or C of A (Certificate of Airworthiness) issued by the Aviation Authority in the country of registration. The airplane must conform with respect to equipment, maintenance and operation to the conditions specified in the certificate. The C of A must be renewed at regular specified intervals. Don't confuse the C of A (which is used for each individual airplane) with the Type Approval, which is issued for the particular *kind* of airplane as a whole.

See Air Reg. 210 to 219 and ANO II No. 4.

AIRPLANE LOGS AND LICENSES

An airplane may not be flown unless there is carried on board the licenses of all members of the flight crew, the Certificate of Registration and the Certificate of Airworthiness of the airplane, the license for the radio equipment installed in the airplane and the Radio Telephone Operator's License of the pilot or other crew member, and the Journey Log of the airplane.

A Journey Log and a Technical Log must be maintained for every airplane. See Air Regs 821 to 825 and ANO VIII No. 2.

PILOT'S LICENCE

No person may fly an airplane unless he is the holder of a valid pilot's licence, (or unless he is the holder of a Student Permit under the supervision of an authorized instructor). If passengers are carried, the licence must be endorsed for the particular type of airplane to be flown and the conditions governing the flight, i.e., day, night, instrument, etc. The airplane must be registered, have a valid C of A (Certificate of Airworthiness) and be certified as airworthy by someone qualified to do so.

A Private Pilot may carry passengers by day in any airplane which has been endorsed on his licence, but not for renumeration. A Commercial Pilot may carry passengers for hire or reward in any airplane endorsed on his licence, that does not exceed 12,500 lbs. Pilots carrying passengers by night must have their licences endorsed for night flying and have made at least 5 night take-offs and landings within the preceding 6 months. No pilot may fly IFR without an Instrument Rating.

DUAL INSTRUCTION

No person is authorized to give dual instruction unless he holds a Flight Instructor Rating. Commercial or airline pilots may, however, give a check out to a licenced pilot on a new type of airplane. Flying time in the log book is entered as Dual, Pilot-in-command, or Co-pilot in accordance with the duties the pilot performed.

RULES OF THE AIR

The few basic rules outlined below do not by any means attempt to cover the entire subject of Air Traffic Regulations. It is vitally important that pilots keep themselves fully informed on current Air Traffic matters by reference to the Circulars issued regularly by the Department of Transport in Canada.

Aircraft meeting head-on both alter course to the right.

An aircraft overtaking another turns out to pass on the right. (This is the only air traffic rule which differs from motor traffic regulations.)

When two airplanes are on converging courses at approximately the same altitude, the airplane that has the other on its right must give way. The airplane that has the right of way should maintain its course and speed, but has, at the same time, a responsibility to take any such action that is necessary to avoid collision.

Based on their ability to maneuver, aircraft have priority for the right-of-way in the following order:

1. Fixed or free balloons.
2. Gliders.
3. Airships.
4. Fixed or Rotary Wing airplanes.

Aircraft in distress have top priority for landing.

An aircraft towing another has priority over other aircraft having mechanical power.

Over cities, towns, congested areas, or open air assemblies, the minimum altitude is "sufficient height to permit an emergency landing without damage to persons or property on the ground", but in any case, not less than 1000 feet above the highest obstacles within a horizontal radius of 2000 feet from the airplane.

Elsewhere than over the areas mentioned above, the minimum altitude is 500 feet.

Aircraft in IFR flight shall not be flown at altitudes of less than 1000 feet above the highest obstacle located within a horizontal radius of five miles from the estimated position of the airplane in flight.

No aircraft may be flown over a jail or penitentiary in Canada at less than 5,000 ft. above the ground without first obtaining permission from the Director, Civil Aviation. (This regulation does not apply in the United States, unless the penitentiary is located within a prohibited area.)

If two airplanes are approaching to land at the same time, the airplane flying at the greater height is responsible for avoiding the lower one.

An airplane on final approach maintaining a straight approach for a landing has the right-of-way over other aircraft approaching to land (except aircraft in distress, which have the landing right-of-way over all others).

Single engine airplanes in Canada may be flown over open water beyond gliding distance from the shore only if they are not engaged in a commercial air service.

NIGHT REQUIREMENTS

DEFINITION OF NIGHT

NIGHT is any period of time during which the centre of the sun is more than 6° below the horizon. That is, for any place, it is the period between the **end** of Evening Civil Twilight and the **beginning** of Morning Civil Twilight. It may be taken as commencing not less than one half hour after sunset and ending one half hour before sunrise.

SUNRISE is when the upper limb (edge) of the sun appears to be on the horizon. SUNSET is when it is about to disappear. Times of sunrise, sunset and twilight at any place on any date may be found in the Air Almanac.

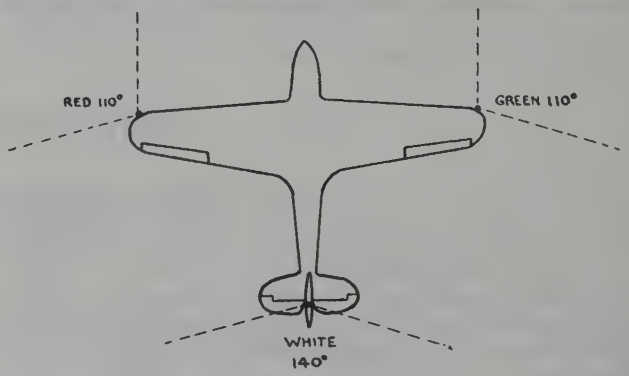
NIGHT EQUIPMENT — AIRPLANES

Aircraft operating at night must be equipped with the following approved, serviceable and functioning flight instruments: an airspeed indicator, a sensitive pressure altimeter, a direct reading magnetic compass, a turn and bank indicator, a gyro magnetic compass or a directional gyro (if the flight is to be conducted beyond the immediate vicinity of the airport), and a means to illuminate the flight instruments. An aircraft that is to be flown within the Northern Domestic Airspace must have on board a means of establishing direction that is not dependent on a magnetic source. Each crew member must have access to a reliable time piece and a functioning flashlight. Any aircraft operating in controlled airspace must be equipped with a functioning two-way radio communication system.

NIGHT LIGHTING — AIRPLANES

Airplanes operating at night, in the air and while maneuvring on the ground, must also be equipped with a functioning navigation light system.

Navigation Lights



SINGLE-ENGINE AIRCRAFT

Fig. 23. Navigation Lights.

On the left wing tip, a steady **red** light and, on the right wing tip, a steady **green** light, each visible for 2 miles from dead ahead through an unobstructed angle of 110°. On the tail, in a position as far aft as possible, a single steady **white** light, visible for a distance of 2 miles through an angle of 140°. (If installation of a single light is impractical, two rear facing steady white lights may be displayed.

An anti-collision light must also be installed on any airplane that will be operated at night. This high intensity flashing light may be either white or red or red/white segmented. It must be visible through 360° and project 30° above and below the horizontal plane of the aircraft.

Navigation lights must be displayed by all aircraft operating at night in Canada, and between sunset and sunrise in the U.S.

Aircraft carrying passengers at night must be equipped, in addition to the equipment mentioned above, with a serviceable and functioning landing light(s).

Between sunrise and sunset, an aircraft moored on the water and anchored to a fixed object either on land or in the water must display a white light visibile in all directions for a distance of 2 miles unless it is moored at a place where aircraft are customarily moored (i.e. a seaplane base).

Anti-collision beacons should not be on while flying in dense cloud because of the possible "flicker vertigo" effect on the pilots. In any event, they should be switched off at the first indication of dizziness.

Fuselage lights, when installed, are white lights mounted on the top and bottom of the fuselage in line, spanwise, with the running lights on the wing tips.

See Air Regs. 556 and 557 and ANO II No. 6.

OVER WATER FLIGHTS

Seaplanes must be equipped with an approved life jacket or individual flotation device for every person on board with several extra in reserve.

A single engine land plane may make an overwater flight if it remains within gliding distance of land. Otherwise, it must be equipped with approved life jackets for all persons on board.

See ANO II No. 8.

AEROBATICS

In Canada, no aerobatics are permitted over cities, towns or on a civil airway. Aerobatics or air exhibitions may be permitted over open air assemblies with the written authorization of the Minister of Transport. In the United States, no aerobatics are permitted over cities, towns or open air assemblies. Over civil airways or within Control Zones, aerobatics may be permitted by a Certificate of Waiver. At air shows, aerobatics will not be permitted at an altitude of less than 1500 feet except by Certificate of Waiver. In any event, the performance of aerobatics must not in any way constitute a hazard to air traffic.

When practising spinning, the recovery from the spin should be made at an altitude not lower than 2000 feet above the ground.

Passengers carried in a U.S. aircraft performing aerobatic flight must be provided with approved type parachutes. In Canada, no passengers are permitted. A flying instructor may, however, fly with a pupil taking aerobatic instruction.

ACCIDENTS

It is the responsibility of the pilot to report flying accidents stating the date, place, extent of the damage, etc., by the quickest means of communication possible to the Aviation Authority of the country in which the accident occurs. When an aircraft is missing, the circumstances must be reported by the quickest possible means.

EXPLOSIVES

Explosives or other dangerous substances may not be transported in an airplane except with permission from the Minister of Transport (Can.).

AIRMANSHIP

Good airmanship involves careful attention to the many facets of preparation for and execution of a flight whether it is a short hop around the circuit or a long cross country flight.

PREPARATION FOR A FLIGHT

Before embarking on any cross country flight, careful preparations and planning should be done.

1. Up-to-date aeronautical charts appropriate for the route of the flight should be obtained and carefully studied to select a route that will take into consideration the nature of the country to be flown over, refuelling points, emergency landing areas, prohibited areas, etc., all of which are factors which influence the selection of a good route. Avoid areas where there is no chance of making a safe forced landing.

If the flight is to be conducted in accordance with visual flight rules (VFR) by contact navigation (i.e. navigating with reference to landmarks), the track selected should be drawn on the map and its direction measured by a navigation plotter. Distance between check points should be measured, using the mileage scale at the bottom of the chart. The track should then be converted from True to Magnetic (applying the variation from the map) and its direction indicated on the map by figures above and below the line. Arrows should be used to distinguish between the track out and home. If the flight is to be a long one, the figures should be spotted in at convenient intervals, allowing for changes in variation and for convergency.

A distance scale should be marked along the track to assist in making groundspeed checks at, say, 50 or 100 mile intervals. Some pilots prefer to mark prominent check points (such as communities, Omnirange Stations, reporting points, etc.).

The character of the country should be carefully studied, particularly as regards high ground and dangerous obstructions. Outstanding landmarks should be noted.

2. Consult the met. forecaster at the airport. Study the Weather Map for wind circulation, frontal activity, and the weather over the whole general area in which you intend to fly. (This knowledge will be valuable in case you have to alter your flight plan to an alternate destination). Check the Terminal, Area and Winds Aloft Forecasts, Hourly Weather Sequences along your route.

3. Select your height to fly, taking into consideration the Winds aloft — High ground and obstructions enroute and in the vicinity of landing fields — Weather Minima for VFR flight — Cruising Altitude Rules.

4. Calculate the True Heading to steer and apply the variation to obtain the Heading Magnetic. Calculate the groundspeed for each leg of the route.

5. Compute the safe and maximum range of your plane. Also the fuel required, based on the estimated times enroute and cruise consumption chart in your Flight Manual. Select refuelling points.

6. Check suitability of airports, runway patterns and field conditions.

7. Note time of sunrise and sunset (VFR).

8. Check radio facilities which are available enroute, and the frequencies on which they operate.

9. Review the latest NOTAMS (Notices to Airmen). Glance over the Airport Bulletin Board.

10. Be sure you are familiar with pertinent flight information such as Navaids — Good Operating Practices — VFR Procedures — Air Traffic Control Procedures — Light Gun Signals — Radio Telephone Phraseology and Techniques — VOR Receiver Check Points — VHF/DF Direction Finding Data and Procedures — Emergency, Search and Rescue, SCATANA Rules — Weather Bureau information, how and where obtainable.

11. Note the location of Control Areas, Control Zones, Airport Traffic Areas and TRSAs — Check Caution, Restricted, Warning and Prohibited Areas — Air Defence Identification Zones (ADIZ).

12. If the flight is to be conducted in accordance with visual flight rules (VFR) but by using only air navigation radio aids, such as Omni, ADF, etc., Enroute Low Altitude Charts and/or the appropriate IFR Charts must be used. These charts contain all the distance and enroute information necessary for flying from point to point by using radio equipment only.

13. Fold maps correctly and place in proper sequence in the cockpit. Be sure to carry other maps for areas adjacent to your line of flight. You may need them if you have to fly around bad weather or become temporarily lost.

14. Be sure that you are properly licenced and qualified for

the particular type of airplane you're flying, and the nature of the flight you are about to undertake.

15. See that the airplane is properly certified, safe and fit for the intended flight. Mandatory manuals and certificates on board. Licences and/or permits carried by members of the crew. See also **"Pilot's Inspection Prior to Flight"**.

16. Fuel of proper grade on board, sufficient for the flight plus 45 minutes reserve.

17. Check the load (all-up weight must not exceed the authorized limit) and the distribution of the load (to insure that the Centre of Gravity is within safe limits). Make sure the load is properly secured and does not block the emergency exits.

18. Check the temperature, and the elevation of the field. Be sure that runway lengths are adequate if high temperature or high altitude conditions prevail.

19. Review the flight load factors and airspeed limitations as outlined in your Airplane Flight Manual.

20. File a **Flight Plan** or a **Flight Notification** with ATC or leave a **Flight Itinerary** with a responsible person.

PILOT'S INSPECTION PRIOR TO FLIGHT

A careful inspection of any airplane should be carried out prior to flight.

This inspection guide is applicable to almost any single-engine or light twin-engine airplane, **provided** it is modified to suit the airplane type and the manufacturer's recommendations. The circled numbers in Fig. 24. correspond to the numbers indicated on the list below. By following the numerically indicated route, a systematic inspection of the airplane can be accomplished.

Stand off and observe the general overall appearance of the airplane for obvious defects.

1. **Cockpit/Cabin.**
   Battery and ignition switches — OFF.
   Control locks — REMOVE.
   Landing gear switch — gear DOWN position.
2. **Fuselage.**
   Baggage compartment — contents properly secured and within the safe C.G. limits, that is, not too far forward or too far back to upset the trim.
   Airspeed static source — free from obstructions.
   Condition of covering — missing or loose rivets, cracks, tears in fabric, etc.
   Anticollision and navigations lights — condition and security.

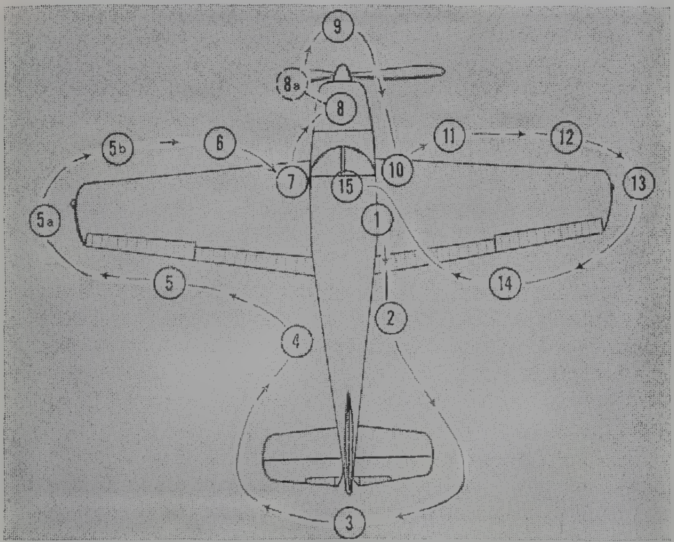


Fig. 24.

3. **Empennage**
   Deicer boots — condition and security.
   Control surface locks — REMOVE.
   Fixed and movable control surfaces — dents, cracks, excess play, hinge pins and bolts for security and condition.
   Tailwheel — spring, steering arms and chains, tire inflation, and condition.
   Lights — navigation and anticollision lights for condition and security.
4. **Fuselage.**
   Same as Item 2.
5. **Wing.**
   Control surface locks — REMOVE.
   Control surfaces, including flaps — dents, cracks, excess play, hinge pins and bolts for security and condition.
   General condition of wings and covering — torn fabric, bulges or wrinkles, loose or missing rivets, "oil cans", etc.

5a. Wing tip and navigation light — security and damage.

5b. Deicer boots — general condition and security.
   Landing light — condition, cleanliness, and security.
   Stall warning vane — freedom of movement. Prior to inspection turn master switch ON so that stall warning signal can be checked when vane is deflected.

6. **Landing gear.**
   Wheels and brakes — condition and security, indications of fluid leakage at fittings, fluid lines and adjacent area.
   Tires — cuts, bruises, excessive wear, and proper inflation.
   Oleos and shock struts — cleanliness and proper inflation.
   Shock cords — general condition.
   Wheel fairing — general condition and security. On streamline wheel fairing, look inside for accumulation of mud, ice, etc.
   Limit and position switches — security, cleanliness, and condition.
   Ground safety locks — REMOVE.
   Seaplanes: floats — remove float covers and inspect for water. Pump out with bilge pump if necessary.
7. **Fuel tank.**
   Fuel quantity in tank — If there is any doubt as to the accuracy of the fuel gauges, look in the tanks.
   Fuel tank filler cap and fairing covers — secure.
   Fuel tank vents — obstructions.
   When fuel tank is equipped with a quick or snap-type drain valve, drain a sufficient amount of fuel into a container to check for the presence of water and sediment.
   Drain cocks — make sure they open and close properly. No drips.
8. **Engine.**
   Engine oil quantity — secure filler cap.
   General condition and evidence of fuel and oil leaks.
   Cowling, access doors, and cowl flaps — condition and security.
   Carburetor filter — cleanliness and security.
   Exhaust stacks — check for cracks and studs for tightness.
   Spark plugs — check terminals for security and cleanliness.
   Engine mount — for cracks and security.
   Drain a sufficient quantity of fuel from the main fuel strainer (often referred to as the "filter bowl" or "gascalator") to determine that there is no water or sediment remaining in the system.
   When closing the cowling, be sure to inspect cowling and baffle seals to assure that they are snug and in place. This is important to assure proper cooling of the engine.

8a. **Nose landing gear.**
   Wheel and tire — cuts, bruises, excessive wear, and proper inflation.
   Oleo and shock strut — proper inflation and cleanliness.
   Wheel well and fairing — general condition and security.
   Limit and position switches — cleanliness and security.
   Ground safety lock — REMOVE.

9. **Propeller.**

   Propeller and spinner — security, oil leakage, and condition. Be particularly observant for deep nicks and scratches.
   Assure that ground area under propeller is free of loose stones, cinders, etc.
10. **Fuel tank.**

    Same as Item 7.
11. **Landing gear.**

    Same as Item 6.
12. **Pitot.**

    Pitot cover — REMOVE.
    Pitot and static ports — remove obstructions.
    General condition and alignment.
13. **Wing.**

    Same at Item 5, 5a, and 5b.
14. **Cockpit.**

    Cleanliness — see that there are no loose articles which might foul controls, or cause distracting noises.
    Windshield and windows — obvious defects and cleanliness.
    Safety belt and shoulder harness — condition and security. See that there is a safety belt for every passenger. Secure belts in unoccupied seats.
    Fire fighting equipment — check cabin fire extinguisher for capacity and ease of release from its holder.
    Emergency exits — not obstructed by disposable load.
    Medical kit — on board and accessible.
    Following documents on board (mandatory) — Certificate of Registration, Certificate of Airworthiness, Journey Log Book, Radio Equipment Licence, Licence of each crew member, Radio Operator's License. Check that C of A is valid and that airplane has been signed out within the required period.
    Adjust rudder pedals so full rudder travel may be assured.
    Parking brake — SET.
    Landing gear and flap switches or levers in proper position.
    Check all switches and controls.
    Trim tabs — SET.
    Pilot's seat — LOCKED.

COCKPIT CHECK PRIOR TO FLIGHT

A systematic and careful cockpit check should also be carried out prior to flight.

1. Do a complete runup of the engine as described in the Chapter **Aero Engines.**
2. Check all instruments systematically (usually from left to right) and adjust each as they are checked if adjustment is necessary. For example: Set altimeter setting on altimeter and check the height indicated as elevation of the airport (plus or minus 50 to 75 feet). If altimeter setting is not known, set airport elevation under indicator needle. Wind the clock and set the correct time. Etc.
3. Check hydraulics to assure proper pressure reading on gauge.
4. Set trim tabs of both elevator and rudder to take-off position according to particular load and C.G. of the airplane.
5. Mixture — Full Rich (unless high elevation of airport requires slight leaning).
6. Carburetor heat — COLD (unless atmospheric conditions necessitate heat).
7. Pitch — Propeller in Full Fine for take-off.
8. Fuel — Check fuel gauge for proper quantity of fuel in each tank, and adjust fuel selector to proper tank for take-off. Adjust cross feed and booster pumps. Primer locked. Be sure that you have enough fuel for the flight you are planning plus a reserve sufficient for forty-five minutes at normal cruising speed. Forty-five minutes reserve fuel is required by Air Regulations.
9. Flaps — Adjust to take-off position.
10. Switches — Magneto ON. Generator ON. Anti-collision beacon ON. Pitot heat, navigation lights etc. as required.
11. Gyros — Adjust Directional Gyro to runway heading. Adjust Artifical Horizon if necessary.
12. Gills — Adjust cowl gills to take-off position.
13. Arm ELT.
14. Safety belts of all passengers and crew fastened. No smoking.
15. Parking brake off. Tail wheel lock adjusted. Water rudders up (seaplanes).
16. Doors or windows or canopy top — Closed and secure.
17. Check freedom of all controls — ailerons, elevators and rudders. While moving the control column and rudder pedals, check that the control surfaces are responding in the proper direction of travel. This check is especially important if the airplane has undergone maintenance during which the control connections have been adjusted or removed and reinstalled. It is not unheard of for the controls to be reinstalled in reverse.

The cockpit check should be made **deliberately without haste.** A definite sequence should be followed, moving clockwise around the cockpit. Touch each control with your hand and name it aloud. For example: "Trim Tabs — Flaps — Fine Pitch", etc., etc. With more advanced types the cockpit check becomes more and more involved. On some large transport aircraft the cockpit check requires several typewritten pages to list. Always work from a **written,** not a memorized check list. You may be interrupted while doing your chores by a radio call, forget where you left off, and overlook some vitally important procedure.

TAKE-OFF PROCEDURE

UNCONTROLLED AIRPORTS

Always taxi downwind to the **extreme end** of the field or runway to take-off. In that way, the full length of the runway is available for the take-off run if it is needed. This practice is a good habit to cultivate. One day, in a short field on a hot day, you will be glad to have every foot of the runway to use. In a seaplane, it is wise to allow at least twice the distance that is really required for the take-off run.

Turn 45° out of wind before taking off to see that no airplanes are immediately approaching to land. Make a final check of the instruments and everything in the cockpit again.

Trim the stabilizer properly for take-off and turn and take-off into the wind.

CONTROLLED AIRPORTS

With Radio

If your airplane is radio equipped, taxi instructions will be given you verbally by the Tower. If you have been given a clearance to taxi to the runway in use, taxi to a position on the taxi strip approximately 100 feet from the boundary of the runway in use to do your engine run-up and cockpit check. (You may taxi across runways without further clearance from the Tower to reach the runway in use unless otherwise instructed). Turn at an angle of about 45° to the taxi strip to do your engine run-up in case there may be another airplane behind you. When you have made your cockpit check, request a take-off clearance from the Tower. (Radio traffic procedures are described in the Chapter **Radio**).

If requesting take-off clearance from an intersection, it is your responsibility as pilot to ensure that the portion of runway available to you is sufficient for the requirements of your airplane. The tower controller bases his authorization on the existing traffic, noise abatement rules, etc., and not the capabilities of your airplane.

If you have approached a runway at an intersection, but wish to back track on that runway to achieve enough runway length for take-off, you must indicate your intentions to the Tower and obtain a clearance for the maneuvre prior to entering the runway.

Sometimes, to expedite the movement of traffic, the controller in giving take-off clearance includes the word "immediate". On acceptance of the clearance, you must taxi onto the runway and take-off in a continuous movement. If, however, in your opinion, this action would affect your operation, you should refuse the clearance and request a static take-off (i.e. a full stop in position prior to starting the take-off roll). There is documented evidence that the loss of an engine on take-off has been caused by an air gap in the fuel system occasioned by the centrifugal force of the tight turn onto the runway leaving the fuel tank line momentarily exposed.

Always turn left after take-off, unless otherwise authorized by the Tower.

Nordo

If your airplane is not fitted with radio, do your engine run-up and cockpit check on the apron **before** taxiing to the runway. (The **apron** is a surfaced area in front of the hangars, which old timers refer to affectionately as the "Tarmac".) When ready for take-off, taxi to a position on the taxi strip approximately 100 feet from the boundary line of the runway in use. Place your airplane in such a position that you have a clear view of the Control Tower. Wait for the steady green light signal to proceed onto the runway, and take-off. At night, switch on your landing light to let the Tower know you are waiting for a signal.

Steady Green Light—Clear to take-off.
Flashing Green Light—Clear to taxi, but do not take-off.
Steady Red Light (or Red Flare)—Stop. Do not taxi.
Flashing Red Light—Taxi clear of the landing area in use.
Flashing White Light—Return to the ramp or hangar.
Flashing Red and Green Light (U.S.)—Danger. Be on alert.
Blinking Runway Lights—Taxi clear of runway immediately.

Acknowledge reception of visual signals by the full movement of the rudder or ailerons of your airplane at least 3 times in succession, or, at night, by a single flash of a landing light.

ENROUTE PROCEDURE

1. Note the time of take-off in the Journey Log. Conform to the traffic circuit procedures for departing the circuit. When well clear of circuit traffic, turn on to the desired heading. Climb to the selected altitude adjusting the power and the mixture in accordance with the manufacturer's operating instructions. During the climb, check the instruments regularly. On reaching the desired altitude, level off and adjust the power and mixture as necessary.
2. Check distance, time and groundspeed by D. R. navigation as detailed in the Chapter **Air Navigation** or by radio aids as detailed in the Chapter **Radio.** Make course corrections and revise expected time of arrival as necessary. Log time over various check points.
3. Fly straight and level when checking headings on the magnetic compass. Reset gyro compass frequently.
4. Avoid thunderstorms. Take appropriate action if unavoidable. Avoid turbulent air if possible. If unavoidable, slow airplane to recommended **Maneuvering Speed.** Do not get stranded over a cloud layer. Avoid the wake of large airplanes.
5. Check the weather as you go by radio or observation. Listen for the weather reports from stations enroute at the published weather broadcast times. Maintain a continuous listening watch for enroute Advisories and SIGMETS. Flight Information Service does provide information regarding unfavourable weather developing along your route, thunderstorms, icing, unserviceability of radio aids, airports or other hazards to safety providing you contact an ATC unit prior to take-off or enroute.
6. Apply carburetor heat, windscreen defroster, wing deicers when necessary.
7. Observe air traffic rules, especially those dealing with ceiling and distance from cloud, visibility, cruising altitudes both on and off airways, weather minima in Control Zones and Control Areas.
8. Keep a constant lookout for other aircraft.
9. Keep an accurate check on fuel consumption, constantly.
10. Observe wind and weather changes.
11. Report to communications stations enroute any unusual weather conditions encountered, or observed, as an aid to other pilots. Reports so transmitted by pilots enroute are referred to as Pireps.
12. Fly around bad weather if possible. If this is impracticable . . . turn back—repeat—turn back.
13. Check your flight and engine instruments frequently. Be sure you understand "altimeter setting" and altimeter errors thoroughly. Compute true airspeed based on indicated airspeed, outside air temperature, and pressure altitude.
14. Report time over intermediate stations enroute. This is good practice if you intend to acquire an instrument rating later on, and it provides Search and Rescue Service with a clue as to your whereabouts if you fail to arrive at your destination. Observe caution in the vicinity of Military Climb Corridors.
15. If the flight is being conducted at a high altitude, calculate the point at which to begin a gradual descent that will result in arrival at the destination airport at approximately circuit height. A gradual descent avoids rapid power off let downs that contribute to carburetor icing. During such a gradual descent, the airplane is able to pick up a bit of airspeed and consequently a better groundspeed which in turn gives a better enroute time.

LANDING PROCEDURE

On approach to destination, contact the ATC facility that is appropriate for that airport (i.e. TRSA, Approach Control, Control Tower) several miles outside the boundaries of the TRSA, Positive Control Zone, Control Zone, etc. If an ATIS broadcast is available, listen to it first and note the information. Follow the instructions of the control facility.

If the airport has no control facilities, keep a careful watch for other traffic and monitor 122.2 MHz or contact the UNICOM of the airport if one is in operation. Observe the wind T or windsock and note the direction of traffic. Conform to the standard procedure for traffic circuits at uncontrolled airports.

PRE-LANDING CHECK

1. Fuel. Check gauges as to contents of fuel tanks. Pressures. Tank selectors, crossfeed, booster pump(s) as required.
2. Parking brake off.
3. Gear down. (Amphibians, as applicable)
4. Water rudders up. (Seaplanes)
5. Mixture rich.
6. Fine Pitch.
7. Carburetor heat. Check. Set as required.
8. Flaps. As recommended.
9. Safety belts fastened. No smoking.

LANDING AND POST LANDING PROCEDURES

1. Keep a sharp look out for other aircraft. Be ready to pull up and go around if necessary.
2. Adhere strictly to approach speeds and flap settings recommended for the airplane.
3. In rain and in winter, be prepared for adverse braking conditions. Many airports prepare Jame Brake Index reports on the condition of the runway and report these to pilots on request.
4. Touch down as near the threshold as possible to have as much runway as possible for the ground run, especially on a slippery runway or when the Density Altitude is high.

5. Be thoroughly familiar with traffic control light signals as they apply to traffic both on the ground and in the air and be prepared to comply with any signal directed to you.
6. Clear the active runway as quickly as possible.
7. Taxi with utmost caution to parking area.
8. Record your flight time.
9. Close your Flight Plan or Flight Notification by filing an Arrival Report with ATC. If Air Traffic Control fails to receive an Arrival Report within a reasonable time, you will be assumed lost and a costly Search and Rescue operation begun.
10. Refuel the tanks and service your airplane.
11. Tie-down securely if hangar storage is not available. Put wing covers and engine covers on if the airplane is to be stored in the open in a cold climate.

WHEELBARROWING

Low wing airplanes with steerable nose gear are most susceptible to the pilot error of wheelbarrowing, although any tricycle gear airplane can be put into this unfavourable attitude.

It occurs when the pilot has inadvertently thrust too much weight onto the nose wheel. Loss of directional or braking control is the usual result.

Wheelbarrowing usually occurs when the pilot uses excess speed while making his approach in a full flap configuration. He may in this situation touch down with little or no rotation and then may try to hold the airplane on the ground with forward pressure on the control column. As a result, the main wheels are carrying insufficient weight for normal braking response. In winter, when snow or ice make the runway pavement more slippery than usual, the problem is compounded.

Some wheelbarrowing accidents have occurred, under strong cross wind conditions, when the pilot is using the slip method of drift correction.

If there is sufficient runway remaining with no obstructions, the best corrective action is probably a go-around. If this is not possible, close the throttle and ease the column to aft of the normal position. This action may lighten the load on the nose gear and put sufficient weight on the main gear to achieve normal braking response.

The chief cause of wheelbarrowing on take-off is the tendency to hold the airplane on the ground with forward control pressure in order to build up a faster than normal groundspeed before rotating.

WIND SHEAR

One of the basic principles of flight is that airspeed is not affected by the movement of the air body itself. This is true except in the situation of wind shear which involves an abrupt or sudden change in wind velocity. Since the inertia of the airplane is far greater than that of the surrounding body of air, there is an inevitable lag in the airplane's response to the sudden increase or decrease of wind, resulting in a temporary gain or reduction in airflow over the wings and therefore in airspeed. The change in airspeed may not last more than a few seconds. In cruising flight, there would be no serious problem but under some landing or take-off conditions, it could be critical.

If, for example, the wind changes suddenly from a no wind condition to a 20 mph tail wind (negative wind shear), inertia causes a several second delay before the airplane reacts to the change in wind during which the airspeed will fall by almost 20 mph. If the airplane is approaching to land at an airspeed near the stall, the approach path could steepen or a stall could occur since any loss in airspeed means a reduction in lift.

Conversely, if a positive wind shear (increase in the velocity of the head wind) of 20 mph takes place, again inertia causes a delay in the reaction of the airplane and the airspeed briefly builds up by about 20 mph. During this brief lag, there is an increase in lift as a result of the increased airspeed, the rate of descent decreases and there is a tendency to overshoot.

The influence of wind shear is related to how quickly an airplane adjusts. It is more pronounced in larger airplanes with large inertia factors than in smaller general aviation airplanes. However, it is a phenomenon that should be understood by all pilots.

GROUND EFFECT

Every pilot has encountered the term ''ground effect''. What exactly is it?

The total drag of an airplane is divided into two components, parasitic drag and induced drag. Induced drag is the result of the wing's work in sustaining the airplane. The wing lifts the airplane simply by accelerating a mass of air downward. It is perfectly true that reduced pressure on top of an airfoil is essential to lift, but still that is but one of the things that contribute to the overall effect of pushing an air mass downward. The more downwash there is, the harder the wing is pushing the mass of air down. At high angles of attack, induced drag is high. As this corresponds to lower airspeeds in actual flight, it can be said that induced drag predominates at low speed.

Ground effect works on wing downwash and wing tip vortices. It tends to reduce the effect of wing tip vortices. This results in a reduction of the airplane's induced drag when very near the ground. At the moment of lift-off, there is about a 48% reduction in the induced drag as compared to that at flight altitude. Induced drag increases rapidly as the plane climbs. At 18 feet altitude there is only about an 8% reduction in induced drag due to ground effect. Trouble occurs when a pilot in trying a take-off from a poor field uses full power and holds the plane in a nose high position. Ground effect reduces induced drag so the airplane is able to reach a speed where it can stagger off. But, as altitude is gained, induced drag increases as the effect of the ground effect diminishes. Twenty to thirty feet up, ground effect vanishes, the wing encounters the full effect of induced drag and the struggling airplane which got off the ground on the ragged edge of stall becomes fully stalled and drops to earth.

A mixture of short runways, rough ground, grass or snow, high airport altitude, high air temperature, a weak engine and a heavy load, in any of many combinations, is the danger signal. When you do find yourself in a marginal take-off situation, know your plane's take-off speed for the conditions prevailing, the distance required to accelerate to that speed, and then allow a generous margin of safety by picking up as much speed as possible just off the ground before trying to climb.

Ground effect works in landing also. In the common case of an airplane coming in with excessive speed, it flys down from free air into ground effect and the reduction of induced drag as it nears the runway comes into effect to make the airplane float. On short fields, approach as slowly as is consistent with safety.

GUST CONDITIONS

A gust or bump increases the load on the wings. The speed of the airplane should therefore be reduced when flying in gusty air.

In approaching to land, on the other hand, a little *higher* speed should be maintained to assure positive control.

A light airplane making a landing in gusty wind should make a **wheel landing.** With this type of landing, the airplane makes contact with the ground while still maintaining flying speed. There is no critical period between positive air control and positive ground control. If the tail is held high until all forward speed has been lost, there is no tendency for a gust to lift the airplane back into the air.

LOW FLYING

Remember the one about the dear old lady who cautioned her son to ''Always fly low and slow''? There is one occasion on which her counsel turns out to be good sound airmanship after all. That is when a pilot is forced to fly low in thick weather. Under these conditions the following precautions should be observed:

Reduce speed because of the limited visibility — but keep a safe margin in case it is necessary to turn fast to avoid a collision. Always keep one hand on the throttle, ready for any sudden emergency.

Keep more than a customary sharp look-out both ahead and on either side.

Remember that it is easy to overestimate actual airspeed when flying low downwind, because of the apparent high groundspeed, and a pilot has therefore a tendency to stall after turning downwind.

It should be noted that the tendency to stall when flying downwind is due to an **optical illusion on the part of the pilot.** The actual stalling speed of an airplane is the same whether flying up-wind or down-wind.

When forced to fly low, detour around any towns or cities that lie along your route.

Flying low in thick weather should only be resorted to, of course, in an emergency, or when authorized to proceed with conditions below VFR minima by an air traffic controller.

VISIBILITY IN RAIN

Rain falling on the windshield of an airplane causes a distortion that will make the terrain contours appear lower than they actually are. A hilltop half a mile ahead may appear to be 200 feet lower than it actually is. This distortion is the result of **refraction.** Light beams are refracted (change direction) as they pass from one medium to another, as from air to water. Water slows up the passage of light and causes it to bend. As a result, objects, terrain, lights appear lower than their actual elevation relative to the airplane. **Diffusion** also causes a distortion. Lights seen through moisture tend to spread apart and appear less intense and therefore farther away. However, on landing approaches, diffusion has a different effect. Approach lights appear larger and therefore nearer. The degree of distortion will vary according to weather and terrain conditions so no rule of thumb applies. Pilots simply must be aware of the phenomenon and when flying in the rain be alert to the problem.

Rain repellant used on the windshield will help reduce the refraction error. Effective windshield wipers also help to reduce the problem.

FLYING THE LAMINAR FLOW AIRFOIL

Laminar flow airfoils, mentioned already in **Theory of Flight,** have certain flight characteristics that the pilot flying them must learn to appreciate. The laminar airfoil takes less energy to slide through the air since it has the advantage of producing less drag.

There are, however, also disadvantages to this type of airfoil. The principle disadvantage is that anything that mars the absolutely smooth surface of the wing, mud splashes, dust and dirt, grime or any foreign material, will reduce the efficiency of the wing much more than would be the case with the same amount of foreign material on a wing of conventional airfoil design.

Pilots flying airplanes with laminar flow wings must be more precise in their technique. Abrupt changes in speed, angle of attack, can suddenly cause large areas of the wing to change from laminar flow to turbulent flow. This can cause large variations in the drag of the wing resulting in "hunting" and "porpoising" especially during low speeds.

An airplane with a laminar flow wing is subject to more abrupt stalls should the angle of attack be increased suddenly. If the stall is approached gradually, the airplane will perform normally. But an abrupt increase in the angle of attack or in g-load can result in a violent stall. For this reason, pilots flying this type of airfoil must be especially careful during landing not to approach with too high an angle of attack near the stalling speed. A sudden disturbance can cause instant stall.

MID AIR COLLISION HAZARD

With the progressive increase in both speeds and traffic density, risk of collision becomes an increasingly serious hazard. For example, a pilot in a high speed executive transport airplane who observes a jet 1½ miles distant on a 90° converging track **has only approximately 7 seconds to take evasive action.**

Seeing, therefore, is a full time job for every pilot regardless of the type of airplane he flies. A pilot must visually scan in all directions constantly.

First of all, learn and practise the procedure for doing an area scan.

Divide the area of forward visibility of your aircraft into sections. Study each in turn carefully. In other words, stop and look in Section A, move to Section B and stop and look, move to Section C and stop and look, etc. A moving target attracts attention but a stationary one does not. On a quick scan, you **will not** see the stationary target, yet **it** is the one which constitutes a potential mid-air collision hazard.

To do a competent scan, the windshield and windows must be clean and free of obstructions, such as solid sun visors and window curtains.

All airplanes have blind spots because of their inherent design: a window frame, the wing or wing strut, the forward fuselage, etc. These blind spots are inevitable but can be compensated for by the pilot.

Never let down, turn or climb into a blind spot. When letting down, turning, or climbing, it is advisable to make a slight "S" turn to have a look before initiating the maneuvre. During prolonged climbs or descents, outside positive control areas, execute gentle left and right banks every few thousand feet in order to broaden your field of vision and also to increase the likelihood of being seen as a result of motion and light reflection.

Sustained periods of straight and level flight outside positive controlled airspace should be broken at intervals by gently banking the airplane in each direction in order to broaden your field of vision.

Be especially mindful of the fact that pilots of high wing and low wing airplanes can be in each other's blind spot. Collisions of this type happen most frequently at uncontrolled airports, when the low wing airplane descends on top of the high wing airplane, especially on final approach or just before touchdown, although it can happen anywhere in the circuit.

When another aircraft is approaching and it has movement, left, right, up or down, there is no danger of colliding. The rate of movement governs the margin of separation. If, however, the other airplane is approaching your track and there is no apparent change in the relative position at which you first saw it, **you are on a collision course** and should take immediate evasive action. Any turn, climb or descent will provide a margin of separation.

An important thing to remember is that **you cannot hit anything that has moved out of the spot from which it was first noticed.** If, however, it becomes stationary at any point, a collision is imminent.

The most common error is turning the wrong way. The rule of turning towards the target and keeping it in sight as long as possible is the rule for visual collision avoidance. By keeping the other aircraft in sight, you remain in control of the situation.

When meeting another aircraft head on, go down and **turn right.** If you are uncertain of his altitude, look for any part of the underwing or upperwing that is visible. Turn right and go down in the first case, turn right and climb in the second case.

Observe rigidly the traffic rules governing flight altitude when flying both on and off airways. Update your altimeter setting as often as practicable.

Be especially alert when flying in areas where traffic is likely to be heaviest — near busy airports especially at lower altitudes and at any height over navigation facilities. When below 3000 feet and within 10 miles of an airport, reduce speed to the minimum airspeed which permits safe control for any necessary maneuver.

When flying cross country, avoid high density areas unless landing.

The use of landing lights greatly enhances the probability of an airplane being seen and thus is an excellent technique to avoid mid-air collisions. Therefore, turn on your landing lights both during day and night, while landing or taking-off, when flying below 2000 feet AGL within terminal areas and in aerodrome traffic circuits, while operating under Special VFR conditions, or in conditions of reduced visibility such as haze or at dusk.

Anti collision lights should be on at any time the engine is running.

If visibility drops below VFR minima and you are not qualified to file an IFR Flight Plan, do not proceed. Land or turn back.

Under an overcast with low ceilings (particularly around 1000 ft.) be careful to avoid approach corridors in the close vicinity of an airport. IFR traffic will be dropping out of the clouds. Approach corridors are shown on Instrument Approach Charts, but if you don't happen to have one, you can roughly estimate the location of an approach corridor by visualizing a line from the radio navigation facility to the runway, extending the line 10 miles outbound from the facility and allowing room for the procedure turn which an airplane doing an instrument approach will make.

Be careful flying on top of cloud. Don't skim the tops. Jets may come barreling up out of the clouds as fast as 6000 fpm. Maintain *one thousand on top*. It is none too ample a margin. This is applicable only to a scattered or broken cloud cover condition. VFR on top of a solid overcast is not legal in Canada.

Aviation Safety Reports have established that air collisions most always happen in *ideal weather*. When you're flying VFR—**look where you are going.** Do not argue the right-of-way. You may be dead right — but if the other pilot doesn't realize it, you may be just dead, period.

GOOD AIRMANSHIP — SOME TIPS

1. Whenever possible, schedule your flight during a time when traffic is least heavy.
2. Be so familiar with the layout of your airplane that you can find and work every control without looking. Practise this blindfolded on the ground until you can do it perfectly.
3. Keep the windows of your airplane unobstructed. Don't put maps and computers in the windows.
4. Keep the windows of your airplane clean.
5. Wear sunglasses on bright days. Do not use opaque sun visors.
6. Be sure you are flying at the correct altitude for your direction of flight.
7. Always look around carefully before starting a turn, while in the turn and after resuming straight and level flight.
8. When climbing or descending, do several clearing turns to check the path of your flight for other airplanes.
9. Keep up a regular routine of scanning the sky around you for other airplanes. Don't forget to do this while concentrating on one airplane. There may be others around also.
10. Keep a watch for older or large airplanes and stay out of their way. Visibility out of these types is usually poor.
11. Give your passengers the job of looking for and pointing out other airplanes in the air.
12. Pay attention to the radio as other pilots call in and report their positions.
13. Be precise in reporting over the geographic location requested by the controller. Call at that point and not two or three miles beyond.
14. Always obey the controller's instructions. Ask to **"Say Again"** if you don't understand. Never acknowledge a transmission if you have not understood.
15. If you fly a high performance airplane, try to slow it down to around 120 mph in the circuit so that your speed matches that of other circuit traffic.
16. Be especially alert when joining the circuit and when turning on final.
17. Be sure to remain VFR and well clear of cloud unless you are cleared IFR.
18. If you are IFR and in good visibility, remember that VFR traffic could be at your altitude and track.

EMERGENCY PROCEDURES

ENGINE FAILURE ON TAKE-OFF

If an engine fails immediately after take-off, land straight ahead — do not attempt to turn back into the field. Some instructors stretch this statement to ridiculous lengths and say that you should glide straight ahead no matter what may lie in your path — even if it means ploughing into a brick wall head-on. It would be interesting to see one of these gentlemen caught with dead engine and a brick wall staring him in the face! Obviously, a good pilot caught in circumstances such as that would attempt to veer somehow and sideslip in on one wing rather than adhere to a rule which would dictate a head-on collision.

ACTION IN THE EVENT OF FIRE DURING FLIGHT

SINGLE ENGINE AIRCRAFT—ENGINE FIRE

1. ★ Mixture Control — IDLE CUT-OFF.
2. ★ Propeller pitch control — COARSE PITCH.
3. Fuel and oil cocks — CLOSED.
4. Operate engine fire extinguisher.
5. Ignition switch — OFF.
6. Throttle — CLOSED.
7. Reduce airspeed.
8. Radio "Mayday". State your position.
9. Make dead engine landing in most suitable area.

TWIN ENGINE AIRCRAFT—ENGINE FIRE

1. ★ Mixture Control — IDLE CUT-OFF.
2. ★ Propeller pitch control — FEATHERED.
3. Fuel and oil emergency shut-off — CLOSED.
4. Operate engine fire extinguisher.
5. Ignition switch — OFF.
6. Throttle CLOSED.
7. Fuel selector switch, booster pump, generator switch, etc. (if fitted) — OFF.
8. Radio "Mayday" and advise your point of intended emergency landing.

★*If fitted. Otherwise begin at 3.*

FUSELAGE FIRE

The modern airplane is not a potential torch as were the early wood and fabric airplanes. Nevertheless fires do sometimes start, usually through carelessness or from electrical short circuits. A means of controlling a fire should be near at hand.

Portable fire extinguishers suitable for combating cabin fires and approved for use are of 3 types: carbon dioxide, dry chemical and water extinguishers.

Extinguishers should be secured in an accessible position with a quick release bracket.

In the event of fire:

1. Select all electrical switches (except ignition)—OFF.

2. All windows, ventilators and cabin air extractors—CLOSED.
3. Apply portable fire extinguishers to source of fire.
4. After fire subsides, leave all switches, except ignition OFF. Land immediately.

DISTRESS SIGNALS

Radio procedures for airplanes experiencing emergencies in flight have been discussed in the Chapter **Radio**.

Certain light signals have been standardized to be used by airplanes in flight to indicate their state of emergency.

DISTRESS, meaning "I am threatened with grave and immediate danger". A succession of red verey lights fired at short intervals or a red flare. SOS flashed with signal apparatus.

URGENCY, meaning "I am compelled to land". A succession of white verey lights by day. Repeated switching on and off of the landing light or navigation lights by night.

SAFETY, meaning "I have an urgent message to transmit". A succession of green verey lights or green flashes with signal apparatus.

The landing light turned on means "I request a clearance to land".

FORCED LANDING

A seasoned pilot will seldom get caught with engine failure without having a forced landing area already selected in his mind. He forms the habit of picking suitable fields as he goes, and constantly checking the wind. As a result, if his engine unexpectedly fails, he immediately knows of a suitable field and is free to concentrate entirely on his approach.

The requirements of a good forced landing ground are:

1. Firm surface, reasonably smooth, with sufficient space to effect a landing into wind. Pasture land is satisfactory because the short grass cannot hide holes, ditches, boulders, or other hazards. Avoid ploughed fields.

2. Approach clear of obstacles such as trees, telegraph wires, high tension lines, houses, etc. Avoid fields immediately alongside highways or railway lines because of wires.

3. Clear take-off run (for when the trouble is corrected).

In winter, if on wheels, it is better to attempt a forced landing on a highway comparatively free of traffic than a deep snow covered field.

If forced to fly over very rough bush country on wheels, it is wise to keep within gliding distance of a highway as a possible emergency landing place. If no such highway exists, by all means pancake into a lake close in to a shoreline, or into muskeg, rather than risk crashing through timber.

Flying seaplanes over land was at one time considered a highly hazardous undertaking. Experimental landings, however, have proved conclusively that a seaplane can be landed in a restricted field with less risk of damage than the average landplane. A pilot should have no hesitation about flying a seaplane overland when necessary, provided good level country lies below, such as would be considered reasonably safe for landplanes.

FORCED LANDING SEQUENCE

Once a pilot has made up his mind to execute a forced landing, he must stick to his decision, even though the engine does pick up again as he nears the ground. Should the engine start up again on the line of approach and should the pilot decide to carry on, there is no guarantee that the engine may not fail again a few moments later when he is no longer in a position to reach a field.

Immediately the engine fails:

1. Reduce speed to gliding speed and set stabilizer — any excess speed can be utilized to gain height.

2. Select a suitable field, check direction of wind, and glide to downwind side of field.

3. Look around for the cause of the engine failure. If it cannot be found and rectified, close the throttle, shut off the switches and gas supply.

4. At downwind side of field, glide cross-wind and look for any obstacles in the field. Decide on landing path.

5. Note drift, which will indicate strength of wind, and lose height by turning — always towards the field — until airplane is in a position at about 1,000 feet, from which a cross-wind approach can be carried out. Turn at about 500 feet into the selected landing line and land into wind. Do not lower the flaps or gear until absolutely necessary, as these increase the drag and **steepen** the glide.

6. Tend to overshoot, and when certain of clearing all obstructions on the downwind boundary of the field, sideslip off the surplus height or lower the flaps. Aim to land well into the field. It is better to overshoot and hit the far fence at low speed than to undershoot and hit the near fence at flying speed.

If the field is hopelessly small or rough for a safe landing, retract the undercarriage and make a "belly" landing.

PROCEDURE AFTER FORCED LANDING

If the forced landing is due to engine failure, examine the tanks to see if there is gas and oil. Check the high tension leads to the plugs to see that they are intact. Examine the filters for dirt. Do not attempt to repair the trouble, if you have located it, unless you are experienced and qualified to do so.

If the failure is repaired, a thorough test of engine performance must be made before attempting to take-off.

If no self-starter is fitted, and it is necessary to get an inexperienced person to assist in swinging the prop, see that he is made familiar with propeller swinging routine before attempting to start the engine. Use wheel chocks.

Never, under any circumstances, have an inexperienced person handle the throttle or switches. The pilot only must operate these when starting an engine.

If the trouble cannot be repaired, and it is necessary to obtain assistance, be sure to have the following information ready to transmit over the long distance telephone or wire:

1. Type of airplane and engine model number.
2. Exact location of the field in which the forced landing was made, and the nearest village or town.
3. Reason for the forced landing, and cause, if it can be ascertained.
4. Whether gas or oil is required for the return trip.
5. Any parts, special tools, or materials required to make the necessary repairs.
6. Whether the forced landing field is suitable for take-off.
7. The type of airplane that may safely land and take-off from the field.
8. The telephone number at which you may be reached.

PRECAUTIONARY LANDING

A precautionary landing is one made with the engine and aircraft functioning normally but when landing is made compulsory due to shortage of fuel, being lost, bad weather, darkness, etc.

If you become lost in smoke, haze, rain, fog or snow, do not fly aimlessly around exhausting your fuel supply. Land immediately and wait until conditions improve sufficiently to enable you to go up and pick up your bearings.

In selecting a field, the same requirements as outlined in selecting a good field for a forced landing should be sought by the pilot.

Having chosen the field, fly over it at least once at low altitude, preferably to one side of the proposed landing path, to check the size and surface of the field, and the suitability of the approaches.

After the preliminary inspection, get into position for a normal engine-assisted approach and landing. Select the flaps down to landing position, if applicable. Approach with as low forward speed as possible (with, however, a safe margin above stalling speed) and aim to touch down as close to the near boundary as is practicable. The aim is to reduce the landing run to the minimum.

If the field is very small, switch off the engine after touching down.

EMERGENCY LANDING PRECAUTIONS

If you have landed with trouble sufficiently serious to preclude all hope of getting away, REMAIN WITH YOUR AIRPLANE. An airplane is a comparatively easy object for search and rescue planes to spot, but a human being in a forest is an almost impossible objective. Remain with your airplane, reserve your energy and conserve your food supply. Start and maintain a smudge fire. Your smoke signal will assist search planes in locating you.

If your radio is serviceable, **use it sparingly.** (Short messages save batteries.) State your position as accurately as you can. You may transmit distress signals on any frequency—but almost all aeronautical communication stations listen on 121.5 MHz and 243.0 MHz. Bear in mind that reception is better at night and there is less traffic on the communication channels.

GROUND-AIR EMERGENCY SIGNALS

1. Make a smudge fire by pouring oil on rags or using green grass, brush wood, or anything to produce heavy smoke to attract attention.
2. Make large SOS in open ground. In snow, outline with boughs or moss.
3. Make trails in virgin snow. These can be readily seen from search airplanes.
4. Lay your cowlings out so they shine in the sun.
5. Keep your aircraft clear of snow or brush.
6. Using radio, call at appropriate times when others are most apt to be listening. Save your battery as much as possible.
7. Point the flashlight at approaching airplanes and flash SOS.

RADAR ASSISTANCE

Radar Assistance is available on a 24 hour basis to all aircraft within the limits of the Identification Zones. This assistance is available to any airplane that is in distress or in an emergency situation. Navigational assistance will be rendered when and wherever possible in the form of position information, vectors or track and groundspeed checks, weather advice, etc. Flights requesting this assistance must be operating within areas of radar and communication coverage and be radar identified.

To request Radar Assistance in Canada, call "**Radar Assistance**" on the frequency listed for the nearest radar facility, or call "**Radar Emergency**" on 121.5 or 243.0 MHz. The following information may be requested:

1. Track and groundspeed checks.
2. Position of airplane (in latitude and longitude, or geographical reference, or direction and distance from a known point).
3. Magnetic Heading to steer to the nearest aerodrome, or other known point.
4. Position of storms or heavy cloud in reference to the aircraft.

If Advisory Service cannot be furnished because of air defence priority, the station will reply "UNABLE".

When requesting service, climb to the best possible altitude. This will improve your chances of being picked up by the radar station.

A pilot who is lost or in distress and unable to transmit radio messages will adopt the following procedure:

If the radio receiver of the airplane is working but the transmitter is inoperative, it is possible to attract the attention of Radar Assistance by flying a triangular pattern such as that shown in Fig. 25. Fly the pattern **to the right.** Hold each heading for 2 minutes. (Jet airplanes will hold each heading for 1 minute.) Repeat the triangular pattern twice. Resume the original heading and repeat the triangular pattern at 20 minute intervals.

If the radio is not operating at all or if the airplane is NORDO, fly the triangular pattern to the **left.**

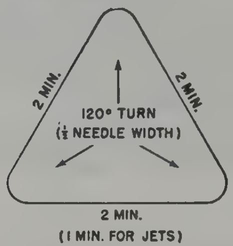


Fig. 25. Triangular pattern for aircraft lost or requiring assistance. If radio receiver is operating, fly pattern to the right or clockwise. If no radio operating, fly pattern to the left or anti-clockwise.

An airplane may be seen as a "blip" on a radar scope, but cannot be individually identified. By flying the prearranged pattern, the radar facility will be able to identify the "blip" that is the airplane in need of help.

A pilot lost or in need of assistance whose radio receiver is working will receive instructions by radio to guide him to the nearest landing place. An airplane whose radio is inoperative will be intercepted by a search and rescue plane and led to the nearest landing field.

Never comply with radar vector instructions intended for another airplane.

BUSH SENSE

The vast hinterlands of Canada and Alaska offer a challenge to the spirit of youth which few other lands the world over can rival. To the sportsman pilot they spell romance — the thrill of the great outdoors, the lure of unfished waters, the zest of virgin forest hunting areas. To the Commercial Pilot, their mining, forest, fur and oil industries offer rare and profitable opportunity.

Flying in the trackless wilderness can be just as safe and practicable as flying the organized airways. Plain, ordinary airmanship — a knowledge of the basic laws, and proper provision for essential needs, are the secrets of the bush pilot's much publicized "sixth sense". Bush sense is, after all, just reasonable proficiency in the handling of seaplanes and skiplanes, plus some fundamental knowledge of the woods.

Flying single-engine airplanes north of the 59th parallel is an undertaking that calls for some special precautions. Airplanes must be capable of 2-way radio communication on 5680 kilohertz, 121.5 and 122.2 megahertz. Also on board must be a portable emergency transmitter capable of operating independently of the aircraft battery. Navigation equipment must include directional gyro and astral compass or gyrosyn compass. A Flight Plan or Flight Notification must be filed when proceeding northbound, entering the Arctic Archipelago, and when returning southbound. Adequate emergency equipment must be on board. Within the Arctic Archipelago, fuel must be sufficient for 500 miles range, plus 45 minutes reserve.

SEAPLANES

Turbulence. Temperature variations between large areas of rock and water in the north country cause turbulence more pronounced than in more settled areas. Shore-line bumps can be sudden and violent. A seaplane approach over a shore-line should be made in a straight line and with a margin of surplus speed.

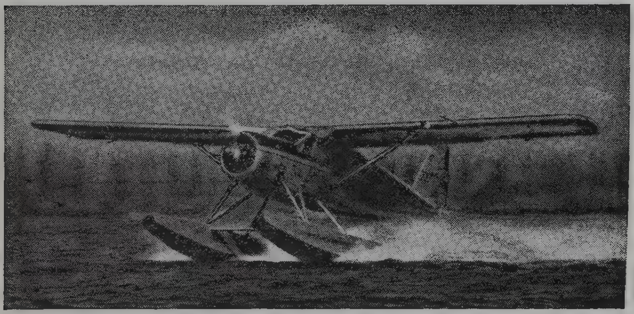
Shore-line bumps also present hazards to take-off. In a strong wind, a very severe down-current of air may be encountered in taking off towards a steep shore-line. Always allow yourself plenty of room when taking off towards a steep rising shore.

T-Effect. When flying over open water in rough air, you may often find a narrow band of calm air approximately 90 feet above the surface. It is known as T-Effect and has helped pilots stretch fuel by increasing airspeed in emergency situations.

Glassy Water. One of the most difficult conditions a bush pilot has to contend with is glassy water. When water is glassy, its surface is practically invisible from above.

1. Try to land alongside a weed bed if one exists within reasonable distance of the landing area. If necessary, land in the weeds. Wild rice is not heavy enough to turn a seaplane over.

2. Land in close to a shore-line, using the shore-line as a guide to the height of the surface of the water. Before doing so "drag" the shore-line at low altitude to look for reefs and shoals.



3. Fly the airplane on by instruments. Make a straight approach down from 300 or 400 feet. Maintain sufficient back pressure on the control column to keep the nose high (to prevent the floats or hull from "digging in" and turning you over). Maintain sufficient power for safe forward speed above the stall, allowing the airplane to slowly "mush" or "sink". On making contact with the water, close the throttle and ease the control column forward gently to prevent the ship from bouncing out of the water.

This method of approach and landing on glassy water should be practised under normal landing conditions at every possible opportunity.

If caught with a dead engine over glassy water and beyond gliding distance of a shore-line or weed bed, do not hesitate to throw the cushions or any movable equipment overboard to make ripples on the water to land by.

Rough Water. Do not attempt "step" landings on rough water. Land **slow.** If gusty weather has necessitated coming in fast, hold off until all surplus speed has been lost. Waves, like sheep, travel in flocks. In very rough water, comparative calm patches can sometimes be found by looking ahead.

Entering a Strange Area. When landing in a strange area, circle the vicinity low several times to look for rocks, reefs or floating timber. If you are not sure of their location when about to take-off, taxi slowly downwind over the area you intend to use on take-off.

The Wind Direction for landing on water can be observed by noting the calm space which always exists on the lee side of the shore-line over which the wind is blowing.

Taxiing. Taxi either very slowly or very fast (up on the step). Taxi speeds in between are critical as they will cause spray to strike the tips of the propellers, causing serious damage, and will also overheat the engine.

Do not approach a dock or rocky shore downwind in a high wind, head-on. Allow the airplane to weather-cock and sail it in tail first, using bursts of engine if necessary to steer it.

Taking Off. A take-off from a very restricted area can be assisted by having persons on the shore hold the tail by a rope until the engine is rev'd up — and then cut it loose.

Another method is to get the plane up on the step downwind and then "skid" around into wind in a wide circle. This maneuver is more applicable to flying boats than seaplanes because of their lower Centre of Gravity.

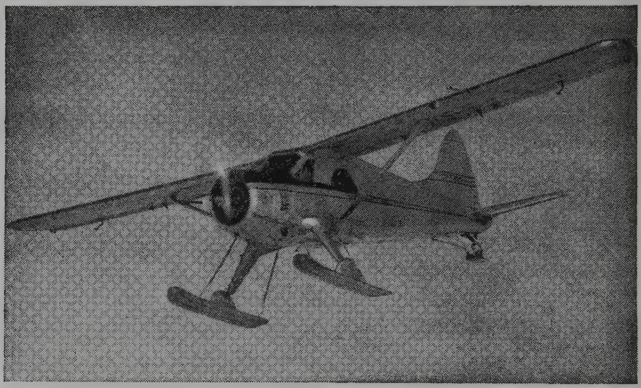
A take-off from glassy water can be assisted by taxiing over the area to make ripples, or having a boat do so.

Immediately after taking off in very cold weather, move the controls to prevent spray from freezing on the control hinges.

SKIPLANES

White-out. An unbroken snow surface with an overcast condition is sometimes as difficult to judge as glassy water. A high wind may cause blowing snow for a height of three or four feet above the surface, similar to ground fog. These conditions are known as **white-out.** If in doubt as to your approach height above the surface, fly the airplane on, using the same method as detailed for glassy water, above.

Soft Snow. If snow conditions are soft, sweep a runway, or make one by taxiing up and down with the airplane lightly loaded before attempting to take-off with a full load.



When taxiing in loose snow, make good wide turns to avoid too much torsional strain on the undercarriage.

If the snow is sticky, oil the skis before taking off. One simple method of doing this is to freeze a couple of bags to the ice. Saturate these with coal oil and taxi over them when about to take-off.

Ice on Wings. Make sure that all surfaces are free from moisture, frost, ice or snow before attempting to take-off. Even a light coating of frost can destroy the lift of the wings sufficiently to prevent a take-off.

Picketing in the Open. Skiplanes can be picketed by freezing the ends of the wing and tail mooring lines into the ice. (Dig a channel in the ice through which the mooring lines can be passed and frozen in.)

When picketing overnight, block the skis up off the ice, or place a mat of evergreen under them. Skis become warm from taxiing, may melt the ice underneath, and by morning become frozen in.

If the ice has become soft and honeycombed, it may be necessary to move the airplane several times during the night. The weight of the airplane generates heat and it may commence to thaw its way through the soft ice.

Landing on Glare Ice. Unless the airplane is fitted with a steerable tail ski or some other form of anti ground-looping device, allow yourself as much room as possible in all directions when landing on glare ice.

Wet and Slushy Snow is similar to mud. With this condition, therefore, always land with the tail well down. In the spring when there is some doubt as to ice conditions on a lake, land out in the middle. The ice is always thickest there (unless there is a current).

EQUIPMENT

The following minimum equipment should be carried by aircraft operating over remote areas in bush country:

SEAPLANES

1 small lightweight folding anchor.
2 wing lines (about 30' long).
1 line (about 50' long) for anchoring, or for tying the tail to a tree or rock when beached on a shore.
1 paddle.
1 bilge pump (for pumping out the floats or hull).
1 engine cover.
1 float repair kit.
Life jackets for all on board.

Some seaplane pilots are lured into a false sense of security because they have equipped themselves and their passengers with life jackets. They reason that if an accident should happen during take-off or landing, everyone in the airplane would be able to swim to shore with the aid of the life jackets. However, it must be remembered that the water in thousands of the Canadian lakes that are frequently used by float planes is so cold that human beings could not survive in it for longer than a few minutes before succumbing to death by exposure.

A gallon pail is not a necessity, but comes in handy. It can be used to store some of the emergency kit, for carrying water, as a drogue (sea anchor) or as an anchor (by filling it with stones).

SKIPLANES

1 snow shovel, ice chisel, snow knife.
2 wing lines (about 15' is ample).
1 line (about 50' long).
1 engine heating tent. This fits completely over the nose and reaches to the ground. It is designed to house a stove for preheating the engine in sub zero weather which is too severe for oil dilution to be effective (below -30°C.).
1 blowpot, or some other form of stove, for preheating the engine and lubricating oil.
1 scraper. For removing frost or ice from the windscreen.
1 set of wing covers.
A tent. (If engine or wing covers are carried they may be used to improvise a tent.)
Small hydraulic jack (for jacking up skis).

ALL BUSH AIRCRAFT

1 fuel funnel and chamois.
1 oil can.
Engine and airframe tools and spares sufficient to effect at least minor repairs.

Most bush pilots carry a small portable semi-rotary pump for refuelling out of gas drums.

Medical Facts for Pilots . . .

The preceding chapters of this manual have been devoted to the technical aspects of flying. The reader should now understand how lift is produced by an airfoil to make an airplane fly, the basic construction of an airframe, all about the operation and care of an aero engine, how to use aircraft communication and navigation radio equipment, how to navigate his way from A to B, the vagaries of weather, etc. etc.

When the first editions of this book were published and, indeed until not too many years ago, it was generally believed that if an individual had a good understanding of all these technical aspects of pilotage, he had acquired the basic pre-requisites to be a successful, efficient and safe pilot.

In the last few years, however, it has been learned that a thorough grasp of these subjects, though essential, is not enough. There is also much to understand about the pilot himself and his physical and involuntary reactions to the unnatural environmental conditions of flying. During the Second World War, it was first realized that some airplane "losses" were due to pilot incapacitation rather than to enemy action. The challenge of explaining these "unusual" occurrences was taken up and since that time much research has been conducted into such subjects as hypoxia, spatial disorientation, hyperventilation, the bends, impairment due to drugs and alcohol, and mental stress. Startling and sobering information is now available.

Man is essentially a terrestial creature. His body is equipped to operate at greatest efficiency within relatively narrow limits of atmospheric pressure and, through years of habit, has adapted itself to movement on the ground.

In his quest for adventure and his desire for progress, man has ventured into a foreign environment, the air high above the ground. But these lofty heights are not natural to man. As altitude increases, the body becomes less and less efficient to a point, at sufficient altitude, of incapacitation and unconscientiousness. Completely deprived of oxygen, the body dies in 8 minutes. Without ground reference, the senses can play tricks, sometimes fatal tricks.

Airplane accidents are an occurrence that every conscientious pilot is concerned with preventing. Most accidents are attributable to "human failure" and all too many of these have been the result of disorientation, physical incapacitation and even death of the pilot during flight. It is the intention of this chapter to explain briefly some of these aeromedical facts to help pilots understand and appreciate the capacities and limitations of their own bodies so that flying might never be a frightening or dangerous undertaking but instead the enjoyable and safe and efficient experience all lovers of airplanes and the airways have always believed it to be.

GENERAL HEALTH

Since flying an airplane demands that the pilot be alert and in full command of his abilities and reasoning, it is only common sense to expect that an individual will ensure that he is free of any conditions that would be detrimental to his alertness, his ability to make correct decisions, and his rapid reaction times before seating himself behind the wheel of his airplane.

Certain physical conditions such as serious heart trouble, epilepsy, uncontrolled diabetes and other medical problems that might cause sudden incapacitation may preclude an individual from being judged medically fit to apply for a license.

Other problems such as acute infections are temporarily disqualifying and will not affect the status of a pilot's license. But they will affect his immediate ability to fly and he should seek his doctor's advice before returning to the cockpit of his airplane.

HYPOXIA

The advance in aeronautical engineering during the past few years has produced more versatile airplanes capable of flying at much higher altitudes than only a few years ago were considered attainable by the private pilot. At such high altitudes, man is susceptible to one of the most insidious physiological problems, **hypoxia.** Because hypoxia comes on without warning of any kind, the general rule of "oxygen above 10,000' ASL by day and above 5000' ASL by night" is one the wise pilot will practise to avoid the hazard of this debilitating condition. Hypoxia can be defined as a lack of sufficient oxygen in the body cells or tissues.

The greatest concentration of air molecules is near to the earth's surface. There is progressively less air and therefore less oxygen (per unit volume) as you ascend to higher altitudes. Therefore each breath of air that you breathe at, for example, 15,000 feet ASL has about half the amount of oxygen of a breath taken at sea level.

The most important fact to remember about hypoxia is that the individual is unaware that he is exhibiting symptoms of this condition. The brain centre that would warn him of decreasing efficiency is the first to be affected and the pilot enjoys a misguided sense of well-being. Neither is there any pain nor any other warning signs that tell him that his alertness is deteriorating. The effects of hypoxia progress from euphoria (feeling of well-being) to reduced vision, confusion, inability to concentrate, impaired judgment, slowed reflexes to eventual loss of consciousness.

EFFECTS ON VISION AT 5000 FEET

The retina of the eye is actually an outcropping of the brain and as such is more dependent on an adequate supply of oxygen than any other part of the body. For this reason, the first evidence of hypoxia occurs at 5000 feet in the form of diminished night vision. Instruments and maps are misread; dimly lit ground features are misinterpreted.

ABOVE 10,000 FEET

It is true that general physical fitness has some bearing on the exact altitude at which the effects of hypoxia will first affect a particular individual. Age, drinking habits, use of drugs, proper rest, etc., all increase the susceptibility of the body to this condition. However, the average has been determined at 10,000 feet.

At 10,000 feet, there is a definite but undetectable hypoxia. This altitude is the highest level at which a pilot should consider himself efficient in judgment and ability.

At 14,000 feet, lassitude and indifference are appreciable. There is dimming of vision, tremor of hands, clouding of thought and memory and errors in judgment. Cyanosis (blue discolouring of fingernails) is first noticed.

At 16,000 feet, a pilot becomes disoriented, is belligerent or euphoric and completely lacking in rational judgment. Control of the airplane can be easily lost.

At 18,000 feet, primary shock sets in and the individual loses consciousness.

At higher altitudes, death may result after a prolonged period.

The Air Navigation Orders rule that an aircraft should not be operated for more than 30 minutes between 10,000 feet and 13,000 feet unless oxygen is readily available for each crew member.

STAGNANT HYPOXIA

Stagnant hypoxia is a condition in which there is a temporary displacement of blood in the head. It occurs as a result of positive g forces, as in an abrupt pull out from a high speed dive and can be attributed to the fact that the circulatory system is unable to keep blood pumped to the head.

PREVENTION OF HYPOXIA

The only way to prevent hypoxia is to take steps against it before its onset. Remember the rule: Oxygen above 10,000 feet by day and above 5,000 feet at night.

OZONE SICKNESS

Another problem associated with flight at very high altitudes is ozone sickness. Although it has been evident only with flights operating at altitudes of 30,000 feet or more, the advent of general aviation airplanes that operate at subsonic speeds at such levels make this a problem of which even the private pilot should be aware.

Ozone is a bluish gas that exists in relatively high concentrations in the upper levels of the atmosphere, especially in the Tropopause. Because the Tropopause fluctuates in its average altitude from season to season, any flight operating above 35,000 feet is likely to come into contact with ozone at some time.

Although ozone does have a distinctive colour and odor, passengers and flight crew who have experienced ozone sickness have been unaware of the apparently high concentrations of ozone prior to the onset of the symptoms.

The symptoms of ozone sickness are hacking cough, poor night vision, shortness of breath, headache, burning eyes, mouth and nose, mild chest pains, leg cramps, fatigue, drowsiness, nose bleed, nausea and vomiting. The symptoms become more severe with continued exposure and with physical activity but do diminish rapidly when the airplane descends below 30,000 feet.

Some relief from the symptoms can be achieved by breathing through a warm, moist towel. Limiting physical activity to a minimum and breathing pure oxygen are also effective in alleviating the symptoms.

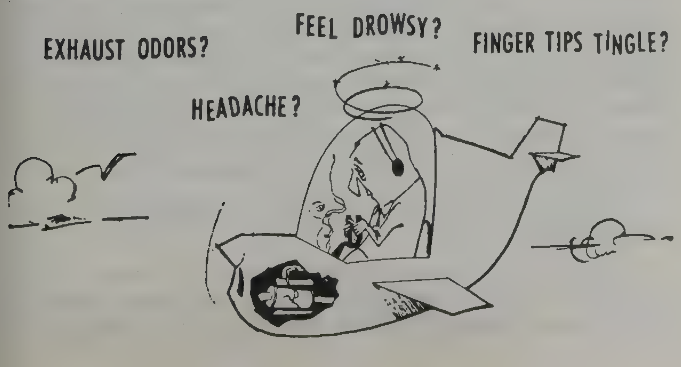
CARBON MONOXIDE

Oxygen is transported throughout the body by combining with the hemoglobin in the blood. However, this vital transportation agent, hemoglobin, has more than 200 times the affinity for carbon monoxide that it has for oxygen. Therefore, even the smallest amounts of carbon monoxide can seriously interfere with the distribution of oxygen and produce a type of hypoxia, known as anemic hypoxia.

Carbon monoxide is colorless, odorless and tasteless. It is a product of fuel combustion and is found in varying amounts in the exhaust from airplane engines. A defect, crack or hole in the cabin heating system may allow this gas to enter the cockpit of the airplane.

Susceptibility to carbon monoxide increases with altitude. At higher altitudes, the body has difficulty getting enough oxygen because of decreased pressure. The additional problem of carbon monoxide could make the situation critical.

Early symptoms of CO poisoning are feelings of sluggishness and warmness. Intense headache, throbbing in the temples, ringing in the ears, dizziness and dimming of vision follow as exposure increases. Eventually vomiting, convulsions, coma and death result.


EXHAUST ODORS?
FEEL DROWSY?
FINGER TIPS TINGLE?
HEADACHE?

Although CO poisoning is a type of hypoxia, it is unlike altitude hypoxia in that it is not immediately remedied by the use of oxygen or by descent to lower altitudes.

If a pilot notices exhaust fumes or experiences any of the symptoms associated with CO poisoning, he should shut off the cabin heater, open a fresh air source immediately, avoid smoking, use 100% oxygen if it is available and land at the first opportunity and ensure that all effects of CO are gone before continuing the flight.

CIGARETTES

Cigarette smoke contains a minute amount of carbon monoxide. It has been estimated that a heavy smoker will lower his ceiling by more than 4000 feet. Just 3 cigarettes smoked at sea level will raise the physiological altitude to 8000 feet. Because the carbon monoxide in the cigarette smoke is absorbed by the hemoglobin, its oxygen absorbing qualities are reduced to about the same degree as they would be reduced by the decrease in atmospheric pressure at 8000 feet ASL.

The carbon monoxide from cigarettes has detrimental effects not only on the smoker but on the non-smoker as well. After prolonged exposure to an increased level of carbon monoxide such as that produced within a confined area such as a cockpit by people smoking, symptoms such as respiratory discomfort, headaches, eye irritation can affect the non-smoker.

Cigarette smoking has as well been declared as hazardous to health, contributing to hypertension and chronic lung disorders such as bronchitis and emphysema and linked to lung cancer and coronary heart disease.

HYPERVENTILATION

Hyperventilation, or overbreathing, is an increase in respiration that upsets the natural balance of oxygen and carbon dioxide in the system, usually as a result of emotional tension or anxiety. Under conditions of emotional stress, fright or pain, a person may unconsciously increase his rate of breathing, thus expelling more carbon dioxide than is being produced by muscular activity. The result is a deficiency of carbon dioxide in the blood.

The most common symptoms are dizziness, tingling of the toes and fingers, hot and cold sensations, nausea and sleepiness.

The remedy for hyperventilation is a conscious effort to slow down the rate of breathing and to hold the breath intermittently to allow the carbon dioxide to build up to a normal level.

DECOMPRESSION SICKNESS

Increased or decreased pressure is also responsible for gas expansion within or on the body, an undesirable and painful effect called decompression sickness.

TRAPPED GASES

During ascent and descent, gases trapped in certain body cavities expand or contract. The inability to pass this gas may cause abdominal pain, toothache or pain in ears or sinuses.

Ear Block

The ear is composed of three sections. The outer ear is the auditory canal and ends at the eardrum. The middle ear is a cavity surrounded by bones of the skull and is filled with air. The eustachian tube connects the middle ear to the throat. The inner ear is used for hearing and certain equilibrium senses.

As one ascends or descends, air must escape or be replenished through the eustachian tube to equalize the pressure in the middle ear cavity with that of the atmosphere. If air is trapped in the middle ear, the eardrum stretches to absorb the higher pressure. The result is pain and sometimes temporary deafness.

During climbs, there is little problem since excess air escapes through the tube easily. However, during descents, when pressure in the middle ear must be increased, the eustachian tubes do not open readily. The pilot and his passengers must consciously make an effort to swallow or yawn to stimulate the muscular action of the tubes. Sometimes it is advisable to use the valsalva

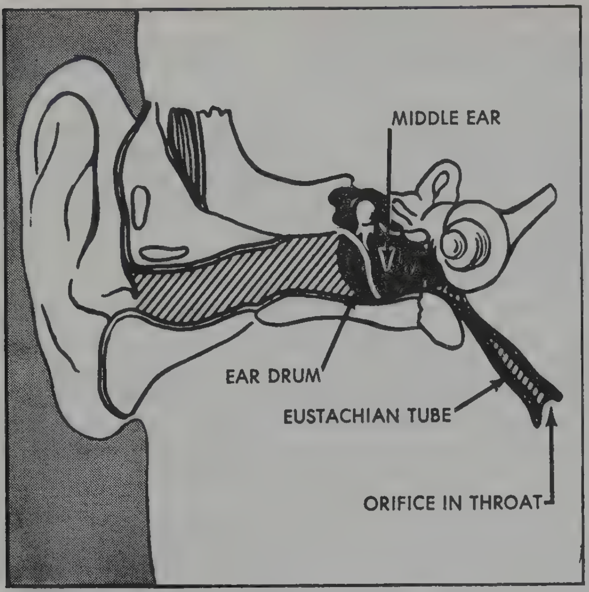


Fig. 1. Ear structure and eustachian tube.

technique, that is, to close the mouth, hold the nose and blow gently. This action forces air up the eustachian tubes. Children may suffer severe pain because of ear blocks during descents. They should be repeatedly reminded to swallow or yawn. Small babies are incapable of voluntarily adjusting the pressure in the middle ear and should be given a bottle to suck during descents.

Painful ear block generally occurs as a result of too rapid descent. If the pilot or his passengers are unable to relieve the pain of ear block by the methods described, it may be necessary to climb to altitude again and make the descent more gradually.

After a flight in which 100 per cent oxygen has been used, the valsalva procedure should be used several times to ventilate the middle ear and thus reduce the possibility of pain occurring later in the day.

Sinus Block

The sinuses are air filled, bony cavities connected with the nose by means of one or more small openings. If these openings are obstructed by swelling of the mucous membrane lining of the sinuses (as during a cold), equalization of the pressure is difficult. Pain in the cheekbones on either side of the nose, or in the upper jaw, or above the eyes, will result.

The valsalva procedure will relieve sinus pain.

For both ear and sinus block, the prudent use of nasal inhalants such as Benzedrex, Afrin, Neosynephrine may be helpful. A nasal inhalant containing antihistamine, however, should not be used for the reasons stated in the section on drugs below.

Toothaches

Toothaches may occur at altitude due to abcesses, imperfect fillings, inadequately filled root canals. Anyone who suffers from toothache at altitude should see his dentist. However, the pain caused by a sinus block can be mistaken for toothache.

Gastrointestinal Pain

''Gas pains'' are caused by the expansion of gas within the digestive tract during ascent into the reduced pressure at altitude. Relief from pain may be accomplished by descent from altitude.

EVOLVED GASES

Nitrogen, always present in body fluids, comes out of solution and forms bubbles if the pressure on the body drops sufficiently as it does during ascent into the higher altitudes. Overweight persons are more susceptible to evolved gas decompression sickness as fatty tissue contains more nitrogen.

Bends is characterized by pain in and around the joints and can become progressively worse during ascent to higher altitudes.

Chokes are pains in the chest caused by blocking of the smaller pulmonary blood vessels by innumerable small bubbles. In severe cases, there is a sensation of suffocation.

Parasthesia or Creeps is another decompression sickness with symptoms of tingling, itching, cold and warm sensations.

Central Nervous System Disturbances include visual disturbances, headache and, more rarely, paralysis and sensory disturbances.

Decompression sickness is unpredictable. One of the outcomes may be ''shock'', characterized by faintness, dizziness, nausea, pallor, sweating and even loss of consciousness. Usually the symptoms disappear when a return to the ground is made. However, the symptoms may continue and special treatment (recompression) may be needed.

Decompression sickness, caused by evolved gas, is rare below 20,000 feet. The best defence against this painful problem is a pressurized cabin. Some protection against it can be achieved by breathing 100% oxygen for an hour before ascending to altitudes above 20,000 feet. This action washes the nitrogen out of the blood. Oxygen does not come out of solution or form bubbles. Refrain also from drinking carbonated beverages or eating gas producing foods.

Scuba Diving and Flying

A person that flies in an airplane immediately after engaging in the sport of scuba diving risks severe decompression sickness at much lower altitudes than this problem would normally be expected. The scuba diver uses compressed air in his breathing tanks to counteract the greater pressure of the water on his body. At a depth of 30 feet, his body absorbs twice as much nitrogen as it would on the ground. Ascending to 8000 feet ASL could bring on incapacitating ''bends''. A good rule, if you have dived to a depth below 30 feet, is not to fly for twelve hours to permit the nitrogen content of the body to return to normal.

VISION

Good vision is of primary importance in flying, in judgment of distance, depth perception, reading of maps and instruments.

Sunglasses should be worn to prevent eyestrain during flights when glare is a problem. At altitude, the atmosphere above is less dense and light is brighter.

Instrument panels should be dull gray or black to harmonize with the black instruments, so that the eye does not have to adjust its lens opening constantly as the line of vision moves from the instruments to a light coloured panel.

When flying into the sun, the eyes are so dazzled by the brightness that they cannot adjust quickly to the shaded instrument panel. This situation causes eyestrain and is fatiguing to the pilot. Sunglasses help to minimize the problem.

Atmospheric obscuring phenomena such as haze, smoke and fog have an effect on the distance the normal eye can see. The ability of the eye to maintain a distance focus is weakened. Distant objects are not outlined sharply against the horizon and after a short lapse of time the eye, having no distance point to fix on, has difficulty maintaining a focus at a distance of more than a mile or two. As a result, scanning for other aircraft becomes difficult and requires special effort on the part of the pilot. With the pilot's focal range reduced, the span of time in which to perceive the danger and take evasive action is considerably shortened. Pilots must learn to recognize the limitations of the human eye under varying weather conditions and realize that the ''see and be seen'' maxim has limitations under some atmospheric conditions.

DEPTH PERCEPTION

Clues for accurate depth perception are often absent in the air. Clouds are of varying size and there is no way to estimate their distance. Landings on glassy water or on wet runways are a problem as is the condition known as "white out" that occurs in blowing snow and other winter situations.

NIGHT VISION

At night the pilot's vision is greatly impaired. It takes 30 minutes for the eye to adjust fully to darkness. Even a small amount of white light will destory the dark adaptation.

Pilots should wear sunglasses during the day and avoid looking at bright lights when they propose to undertake a night flight. Wearing red goggles for 30 minutes prior to a night flight helps the eyes adapt to darkness.

Night vision is also sensitive to hypoxia. Supplementary oxygen should be used above 5000 feet to avoid depriving the eye of oxygen.

Dirt and reflexion on the windshield cause confusion at night. A very clean windshield is important.

Night Lighting of Instruments

Lighting of instruments is a problem in that the instruments must be well enough lit to be readable without the light destroying the pilot's dark adaptation.

Ultraviolet Flood Lighting of Fluorescent Instrument Marking is probably the least satisfactory. The instruments are marked with fluorescent paint that shows up under fluorescent lighting as a bluish green colour. The disadvantages are that the instruments can't be kept in focus, dark adaptation may be lost, eyes are irritated, vision becomes foggy.

Red lights. Lighting of instruments by indirect individual red lights is unsatisfactory because uniform light distribution over all parts of the instrument cannot be achieved. There is no illumination of knobs and switches. Red flood lighting of the whole instrument panel is more satisfactory. However, the ability to distinguish colours one from another is lost. Colouration of maps is indecipherable and information printed in red becomes unreadable.

White Lights. Low density white light is considered the best cockpit lighting system. The instruments can be clearly read and colours recognized. Because the low density white light can be regulated, dark adaptation is not destroyed although it is somewhat impaired.

THUNDERSTORMS

It is not advisable to fly an airplane through or near thunderstorms. The blinding flashes destroy night adaptation.

ANTI COLLISION LIGHTS

When flying in the clouds, strobe lights and rotating beacons should be turned off as the reflection off the cloud of the blinking light is irritating to the eye.

FLICKER VERTIGO

When letting down for a landing into the setting sun with a single engine airplane, the idling propeller can induce what is known as Flicker Vertigo. This is a malady caused by the flickering shadows inflected on the vision. Reactions range from nausea to confusion and sometimes to complete unconsciousness. Avoid landing into the late afternoon sun if possible, but if you have to, and notice any strange sensations, buzz your engine and kick on rudder. Other causes of Flicker Vertigo are helicopter rotor blade shadows, the flashing illumination caused by anti-collision lights when flying in cloud, and runway approach strobe lights when viewed through the propeller at night.

NOISE, VIBRATION AND TEMPERATURE

Noise

Noise is both inconvenient and annoying. It produces headaches, visual and auditory fatigue, air sickness and general discomfort with an accompanying loss of efficiency. Even at levels which are not uncomfortable, noise has a fatiguing effect, especially when the pilot is exposed for a long period as on a lengthy cross country flight. To arrive at destination suffering from noise induced fatigue and have to make a landing under minimum conditions is clearly an undesirable situation.

Noise levels in the range of 130 decibels or above are very dangerous and should not be experienced without ear protection. (The unit of sound intensity or loudness is called the decibel or db.) Yet, little has been done to reduce and control noise in aircraft cockpits. Tests have measured the sound level in modern aircraft at 90 to 100 decibels. Noise levels in jets can approach 140 decibels.

With noise levels of this magnitude, hearing damage is a distinct problem unless some sort of hearing protection is used. Many pilots report temporary losses of hearing sensitivity after flights. Still others have reported an inability to understand radio transmissions from the ground especially during take-off and climb when the engine is operating at full power. In fact, there is documented evidence to show that continued exposure to high levels of aircraft noise will result over the years in loss of hearing ability.

The detrimental effect of noise is not a sudden thing but builds up progressively over years of exposure. Pilots of helicopters and aerial application aircraft are particularly susceptible because of the relatively high levels of noise experienced in these cockpits and the long durations of exposure. But even pilots, who put in only three or four hours a week in their airplanes have been found to have slightly impaired hearing after several years.

Protective devices against noise are therefore important, first of all, in helping to reduce fatigue during individual flights and, secondly, in helping to minimize the possibility of hearing loss or deterioration in later years.

The best protection is a pair of properly fitting earplugs. They lower noise levels by as much as 20 to 30 decibels. The use of ear covering devices, such as earphones, can also help if they are tight fitting. If they fit poorly, they can be worse than nothing in that they give the wearer a false sense of security. The use of earplugs as well as earphones is recommended.

The wearing of earplugs does not impair ability to hear. In fact, speech intelligibility is improved for the earplugs filter out the very noises that interfere with voice transmissions.

The regular wearing of earplugs, especially by pilots but also by passengers, is therefore a good precautionary measure to ensure continued good hearing throughout a pilot's lifetime.

VIBRATION

The power plant of the airplane is the principal source of vibration. At subsonic speeds, this vibration is responsible for fatigue and irritability. If the vibration happens to occur in the frequency of about 40 cycles per second, the eyes will blur. It is even possible to become hypnotized as a result of rhythmic and monotonous vibrations.

TEMPERATURE

At temperatures over 30°C, discomfort, irritability and loss of efficiency are pronounced. High temperatures also reduce the pilot's tolerance to mental and physical stresses, such as acceleration and hypoxia.

At cold temperatures, the immediate danger is frostbite. Continued exposure will result in reduced efficiency to the point where safe operation of the airplane is impossible.

SENSORY ILLUSIONS

Under normal conditions, the eyes, inner ears and skeletal muscles provide the brain with information about the position of the body in relation to the ground. In flying, however, conditions are sometimes encountered which fool the senses.

The eyes are the prime orienting organs but are dependent on reference points in providing reliable spatial information. Objects seen from the air often look quite different than they do when seen from the ground. If the horizon is not visible, a pilot might choose some other line as reference, such as a tilted cloud bank. Fog and haze greatly affect judgment of distance. Lights on the ground at night are commonly confused for airplanes. Even stars can be confused with ground lights.

The tension of various muscles in the body assists in a small way in determining position. The body is accustomed to the pull of one g force acting in only one direction. In an airplane, if a second force exists as in acceleration, deceleration and turns, and if there is no outside visual reference, illusions may result. For example, in a bank, both centrifugal force directed outward and the normal downward pull of gravity combine to give an illusion of level flight. Acceleration gives an illusion of climbing and deceleration of diving.

The three semicircular canals of the inner ear are primarily associated with equilibrium. They are filled with fluid and operate on the principle of inertia of fluid. Each canal has tiny hair like sensors that relate to the brain the motion of the fluid. Rotation of the body tends to move the fluid, causing the displacement of the sensors which then transmit to the brain the message of the direction of their displacement. However, if the turn is a prolonged and constant one the motion of the fluid catches up with the canal walls, the sensors are no longer bent and the brain receives the incorrect message that the turning has stopped. If the turn does then indeed stop, the movement of the fluid and the displacement of the sensors will indicate a turn in the opposite direction. Under instrument conditions or at night when visual references are at a minimum, incorrect information given by the inner ear can be dangerous.

Refer to the attitude instruments constantly when flying at night or in reduced visibility conditions.

Always trust the attitude instruments no matter what your senses tell you.

SPATIAL DISORIENTATION

Spatial disorientation means loss of bearings or confusion concerning one's sense of position or movement in relation to the surface of the earth. Disorientation rarely occurs without reduced visual references in such situations as fog, cloud, snow, rain, darkness, etc.

VERTIGO

Vertigo is a sensation of rotation or spinning, an hallucination of movement of either the individual himself or of the external world.

CORIOLIS EFFECT

Coriolis Effect is probably the most dangerous type of disorientation. The three semicircular canals of the inner ear are interconnected. If movement is occasioned in two of them, a sympathetic but more violent movement is induced in the third. This is known as tumbling and causes extreme confusion, nausea, and even rolling of the eyeballs that prevents the pilot from reading correctly the airplane instruments. This situation can occur if, when the airplane is in a turn, the pilot suddenly turns his head in another direction. The rule should always be to avoid head movements, especially quick ones, when flying under instrument conditions.

ALCOHOL

Alcohol, taken even in small amounts, produces a dulling of judgment, comprehension and attention, lessened sense of responsibility, a slowing of reflexes and reduced coordination, decreases in eye efficiency, increased frequency of errors, decrease of memory and reasoning ability and fatigue.

Alcohol is absorbed very rapidly into the blood and tissues of the body. Its effects on the physiology are apparent quite soon after ingestion and wear off very slowly. In fact, it takes about 3 hours for the effects of 1 ounce of alcohol to wear off. Nothing can speed up this process. Neither coffee nor hard exercises nor sleep will minimize the effects of alcohol.

BLOOD-ALCO CHART

SHOWING ESTIMATED % OF ALCOHOL IN THE BLOOD
IN RELATION TO BODY WEIGHT

DRINKS		1	2	3	4	5	6	7	8	9	10	11	12
BODY WEIGHT	100 lb.	.038	.075	.113	.150	.188	.225	.263	.300	.338	.375	.413	.450
	120 lb.	.031	.063	.094	.125	.156	.188	.219	.250	.281	.313	.344	.375
	140 lb.	.027	.054	.080	.107	.134	.161	.188	.214	.241	.268	.295	.321
	160 lb.	.023	.047	.070	.094	.117	.141	.164	.188	.211	.234	.258	.281
	180 lb.	.021	.042	.063	.083	.104	.125	.146	.167	.188	.208	.229	.250
	200 lb.	.019	.038	.056	.075	.094	.113	.131	.150	.169	.188	.206	.225
	220 lb.	.017	.034	.051	.068	.085	.102	.119	.136	.153	.170	.188	.205
	240 lb.	.016	.031	.047	.063	.078	.094	.109	.125	.141	.156	.172	.188

The actual blood alcohol is altered by rate of absorption which depends on many variables, such as type of drink, previous food, etc.

The average rate of decrease of blood alcohol (primarily by metabolism) is .015% per hour. Therefore, 15% would require approximately ten hours to reach zero.

Depending on the extent of after effects (hangover) one cannot state that a negligible blood alcohol is necessarily commensurate with best preformance capability.

The presence of alcohol in the blood interferes with the normal use of oxygen by the tissues. Because of reduced pressure at high altitudes and the reduced ability of the hemoglobin to absorb oxygen, the effect of alcohol in the blood, during flight at high altitudes, is much more pronounced than at sea level. The effects of one drink are magnified 2 to 3 times over the effects the same drink would have at sea level.

A pilot should never carry a passenger that is under the influence of alcohol. Such a person's judgment is impaired. His reactions during ascent to higher altitudes are unpredictable. He may become belligerent and unmanageable and a serious hazard to the safety of the flight.

The rule for both pilot and passengers in relation to alcohol quite simply should be **"No alcohol in the system when you fly"**.

DRUGS

Drugs, as well as the conditions for which they are taken, can interfere with the efficiency of the pilot and can be extremely dangerous. Even over the counter drugs such as aspirin, antihistamines, cold tablets, nasal decongestants, cough mixtures, laxatives, peregorics, tranquilizers and appetite suppressors impair the judgment and co-ordination. They are responsible for drowsiness, dizziness, blurred vision, confusion, vertigo and mental depression. The effects of some drugs are even more pronounced at higher altitudes than on the ground. Some prescription drugs, such as antibiotics, are equally or more dangerous. Usually, however, a person sick enough to be on antibiotics is too sick to be flying.

Antihistamines. (For allergic disorders). Cause sedation with varying degrees of drowsiness, decreased reaction time, disturbances of equilibrium. Do not pilot an airplane within 24 hours of dose.

Sulfa Drugs. Cause visual disturbances, vertigo, impaired reaction time, depression. Remain off flying for 48 hours.

Tranquilizers. Affect reaction time, concentration and division of attention. U.S. military pilots get grounded for 4 weeks following treatment.

Aspirin. Not more than 2 tablets per day.

Reducing Drugs. Amphetamines and other appetite suppressing drugs cause feelings of well being that affect good judgment.

Barbiturates. (including Phenobarb.) Noticeably reduce alertness. Do not pilot an airplane within 12 hours of treatment.

Anaesthetics. Following local and general dental and other anaesthetics, a period of 48 hours should elapse before flying.

BLOOD DONATIONS

Because it takes several weeks for the blood circulation to return to normal after a blood donation, it is recommended that pilots who are actively flying refrain from volunteering as blood donors. A minimum of 72 hours should elapse before flying again if a blood donation has been made.

FATIGUE

Fatigue is one of most common physiological problems for aircrew members and will adversely affect individuals who are otherwise in good health. Fatigue degrades performance. A tired pilot cannot carry out his tasks as reliably and accurately as he should. He is irritable and less alert, willing to accept lower standards of accuracy and performance.

Fatigue begins when the pilot begins a flight and increases with each hour in the air. As a result, at the time of landing when his reflexes and judgment should be keenest, the pilot is most affected by the cumulative effects of fatigue.

The onset of fatigue is accompanied by numerous symptoms: deterioration in timing of movements, irritability and lack of patience, a tendency to lock the attention on individual instruments rather than to see the instrument panel as a whole, a tendency to become forgetful and ignorant of relevant cues, a tendency to overcontrol the airplane, an awareness of physical discomforts, a loss of ''seat of the pants'' flying ability.

Fatigue is caused by many things — lack of sleep, stress, prolonged and repeated flights, aircraft noise, workload and working conditions, boredom, monotony, night flights, frustrations from work and family.

Many of the causes of fatigue are avoidable and many of the symptoms recognizable. Awareness of the problem is the pilot's best help in fighting it.

EATING

The stresses of flying, or indeed of any activity, consume energy. This energy is derived from oxygen and from blood sugar. The pilot is unwise to fly for too long without eating. His blood sugar will be low; that is, his energy reserve will be low. Reactions will be sluggish and efficiency will be impaired. It is a good precaution to carry a snack on long flights.

Overeating is equally as unwise as not eating. Drowsiness and excessive gas formation are the result of over indulgence at the dinner table just before a flight.

At altitudes above 5000 feet ASL, the body experiences a higher loss of water through the surface area of the lungs than it does at sea level. This loss occurs because the percentage of water vapour in a given volume of air decreases with altitude. Because this water loss is not accompanied by a loss of salt, as occurs with perspiration, there is no accompanying sensation of thirst. Especially on long flights at higher altitudes, it is advisable therefore to have a drink of water every hour or so to replace the lost body fluid.

EMOTIONAL STRESS

Flying fitness is not just a physical condition. It has a definite meaning in the psychological sense as well. It involves the ability of the pilot to perceive, think and act to the best of his ability without the hindering effects of anger, worry and anxiety.

Studies have shown that emotional factors, mental upsets and psychological maladjustments are repeatedly present in airplane accidents. The ability to think clearly and act decisively are greatly influenced by the feelings and emotions. In fact, every individual will panic earlier than normal if he is suffering from fatigue, illness, worry or anger. But, even well away from the panic threshold, good judgment is seriously impaired under emotional stress.

If an argument with your spouse or your boss is still rankling, if worries are building up to an unbearable load, if you have been despondent and moody, the cockpit of your airplane is probably no place for you.

PANIC

There are many things that can happen in the air that cause fear and anxiety. These are normal reactions to a predicament that is out of the ordinary. What is to be avoided is allowing that normal anxiety to progress to **panic.**

Panic is a complete disregard for reason and learned responses, a feeling of extreme helplessness. A pilot in the grip of panic will freeze at the controls, will make a totally wrong response or succumb to completely irrational action.

Fatigue, hangover, emotional stress, chronic worry, illness, all substantially reduce the amount of anxiety an individual can withstand before he succumbs to panic.

The best way to prevent panic is through training and frequent rehearsal of emergency techniques. A pilot who knows his emergency routines so well that they are automatic will be less likely to panic when faced with a real emergency situation.

Lack of self confidence is, in itself, self defeating and an open door to panic. Not that a pilot should be fearless, for the fearless pilot has suspended reality-testing. He refuses to admit that there is any situation into which he is not competent to venture. Self confidence is quite another thing. The self confident pilot can assess the reality of a situation, can call on his reserves of training and knowledge to cope with the situation and does not permit emotion to cloud his reason.

PHYSICAL FITNESS

The purpose of this book has been to instruct the pilot in what he should know to be a competent aviator. What he should do is, however, of equal importance. The most competent, knowledgeable and experienced pilot is in business only so long as his medical is valid. Maintaining physical fitness is therefore of prime importance.

Throughout the flying fraternity, there are thousands of pilots in their senior years who are still enjoying the privileges of their licence and using their airplane for pleasure, business and travel. If you want to be flying when you are eligible for the old age pension, now is the time to start looking after your health and maintaining your physical fitness.

The person who is physically active, participating in a regular routine of exercise or sports, will most likely have a healthy heart, lungs and not be overweight. Diet is important, not only to keep weight at an acceptable level, but also in the control of heart disease. The case against smoking as a contributor to lung disease and heart disease is heavily documented. Protection of hearing by wearing earplugs has already been mentioned as has the need to protect the eyes from undue eyestrain.

Air Safety . . .

What do we mean by Air Safety? In essence, Air Safety is the putting into practice of all that knowledge on aviation and technical matters that a pilot has acquired in the course of his aeronautical training and flying career. It is, in other words, perpetual and continued **concern** for the well being of and **respect** for the personal property and endowed rights of our fellow men as well as of ourselves. It is based on sound judgment and a thorough knowledge of the subjects which have been dealt with between the covers of this manual. However, the ultimate in flight safety is more than just the possession of **knowledge.** It is also the exercise of **common sense** and, perhaps what is more important, of **self discipline,** that is, the self discipline to apply the knowledge and the common sense in a positive attempt to do the right thing or make the right decision at the right time regardless of other distracting and prejudicial influences. The safety conscious pilot bases his decisions on good judgment rather than on emotional or impulsive whims.

For a lifetime of pleasant and safe flying, not only must a pilot have an appreciation of the foundation on which "the rules of flight" were built, but he must also practise these rules at all times.

Government aviation agencies and flight safety experts all agree that the biggest challenge they face is that of making each pilot aware of his own limitations based on his knowledge and experience or, to be more explicit, based on his lack of knowledge and inexperience. The conclusions reached by accident investigators tend very substantially to support the widely held opinion that almost every pilot, who has found himself in trouble while at the controls of an airplane, got into his predicament either because he had insufficient appreciation of the degree of competence and skill required during a particular flight or because he over-estimated the limitations of his own ability to cope with the conditions he knew he would encounter.

It is important, therefore, for pilots to realize not only the value of securing adequate training but also how much re-training they need and how frequently they need such re-training in order to execute their pilot-in-command responsibilities adequately, efficiently and with the maximum amount of safety during flight. It is important for every pilot to review, review and review again those basic aeronautical fundamentals to be sure that he does not forget the essentials which are important for safe flying. He should never give up trying to learn more about aviation and flight safety. No one really ever graduates from "a course in flying". The acquisition of knowledge goes on forever. The wise pilot knows that "When you think you've learned all that there is to know about flying, then it's a sign that you'd better quit flying." The pilot who flies an airplane as a hobby still requires the skill of the professional pilot and must approach his flying with equal earnestness.

It is important that every pilot should feel a sense of responsibility both to himself and to all his fellow pilots. All pilots share the same airspace and an error in judgment by one can have serious detrimental effects on others. Don't be considered a hazard to yourself and to others.

THE PROPER STATE OF MIND

Possessing the proper mental attitude towards piloting an airplane is the prime factor governing safe flying where the pilot is concerned. It governs all of his actions. With the proper state of mind, a pilot is able to make correct judgments as to what are and what are not the important considerations at hand, where emphasis should be placed, what are the pros and cons of various courses of action. Pilots possessing the proper state of mind are positive while being open-minded; they are confident in their judgment because they are aware of their own shortcomings, limitations of knowledge and experience, and because they respect their reasonable doubts. They are self reliant but are not dogmatic in believing in their inability to be wrong. Confidence without doubt is over-confidence. Freedom from inhibitions and complexes and worries is the pilot's ultimate goal if he is to be a safe pilot. The problems of his personal world do not belong in the cockpit of his airplane. If safety in flight depends on the pilot's actions in his cockpit, then it is easy to realize the importance of directing his whole attention and concentration, free of extraneous problems and thoughts, to the tasks of flying the airplane. A thinking and responsible pilot cares about his mistakes and avoids repeating them. A pilot possessing the proper mental outlook will not hesitate to turn back when encountering bad weather. He has no wish to run the risk of being a statistic in the next morning's newspaper.

The rules and maxims listed below are the product of the wisdom of experienced pilots and experts in aviation safety. They are not new or startling but are rules that wise pilots have memorized and practised for years. If followed, they will give you too thousands of safe flying hours and many years to enjoy those things in life that you value and enjoy most of all.

MAKE THESE RESOLUTIONS

1. I shall look upon the licence to fly as a privilege to which I shall be entitled only as long as I execute this privilege strictly within the limits of my ability and experience.

2. I shall conduct a thorough inspection of my airplane prior to every flight and I shall refrain from flying in any airplane with a known operational defect.

3. I shall check the weather prior to every cross-country flight and, when filing a Flight Plan, shall remember to close it upon the arrival at my destination.

4. I shall carry passengers only in an airplane with which I am familiar and in which I have had adequate recent experience.

5. I shall not plan any flight beyond the limits which can be reached under prevailing wind conditions with 3/4 of the fuel on board and I shall land at the nearest available airport when my fuel supply indicates one hour remaining.

6. I shall fly at legal altitudes at all times and refrain from making unauthorized low passes, hedge-hopping, buzzing and similar childish stunts which constitute a danger to myself and others.

7. I shall report unusual weather and atmospheric conditions as soon as possible to the nearest radio facility.

8. I shall refrain from flying close to or entering into weather conditions considered marginal with reference to my capabilities, experience and the equipment aboard the airplane.

9. I shall offer to yield landing priority to jet airliners and other high-speed airplanes when in the traffic circuit of an airport serving scheduled airlines.

10. I shall personally supervise refuelling, tie-down and other ground servicing activity which may affect the safety of persons and equipment.

11. I shall refrain from entering an airplane when recently having partaken of drugs, alcohol or other debilitating substances, when not having had any sleep during the preceding 16 hours or when physically or mentally impaired for any reason whatever.

12. I shall conduct myself in the process of operating an airplane and at all other times in a manner giving a favorable impression of aviation and the flying community.

OBEY THESE 12 IMPORTANT RULES

1. CHECK OUT — Plan ahead so that you never attempt

to exercise the privilege of your pilot certificate in any airplane unless checked out by a well-qualified instructor and having successfully completed a minimum of

(a) One hour ground familiarization with controls/systems and airplane operating limitations.

(b) 8 regular take-offs and landings (day or night).

(c) 2 short field take-offs and landings.

(d) 2 cross wind take-offs and landings.

2. PRE-FLIGHT — Plan ahead so that you never start the engine until

(a) You have checked weight and balance data.

(b) You have made sure any objects carried in the passenger cabin are properly secured and free of the controls.

(c) Prescribed "walk around" preflight inspection completed.

(d) Fuel quantity double checked for proposed flight plan plus 15 minutes for take-off plus 45 minutes reserve.

(e) Fuel contamination checked into transparent container from under engine and wing tank quick drains.

3. VIGILANCE — Plan ahead so you never occupy any area on the ground or in the air without "double checking" for possible existing or potential hazards.

4. CONTROLS AND SYSTEMS — Plan ahead so that you

(a) Never operate an airplane unless you are thoroughly familiar with the operation and correct use of all controls and systems.

(b) Never start engine, start take-off, start landing, start cruising, or start let-down until all prescribed procedures are accomplished from memorized "check list" and immediately thereafter "double-check" against written "check list".

(c) Never attempt to operate an airplane with known malfunction. If malfunctioning in flight, head for nearest airport.

(d) Never raise flaps after landing retractable gear airplane until well clear of the active runway, and only after "double-checking" the control you are activating.

(e) Are always alert for the formation of carburetor ice. Use full carburetor heat at the first indication of carburetor icing.

5. WEATHER — Plan ahead.

(a) Pre-flight — Weather study establishing "enroute forecast", "enroute conditions" and "escape route" to good weather.

(b) In-flight — Never get even close to losing good "ground reference" control — when encountering 1000 feet or 5 miles, plan retreat to good alternate airport and execute retreat encountering 800 foot ceiling or under 3 miles visibility. (Unless current and qualified for IFR)

(c) On Top — Never, except over widely scattered clouds, and then only provided there is at least 2000 feet from highest ground to cloud base. (Unless current and qualified for IFR)

(d) Night — Never, unless assured of 2000 foot ceiling and 5 miles visibility and assured that no frontal or ground fog, or storm conditions will be encountered. (Unless current and qualified IFR)

6. SPEED/STALL CONTROL — Plan ahead so that you never abruptly change attitude of airplane nor allow airspeed to drop below

(a) At least 160% of stall speed when maneuvring below 1000 feet.

(b) At least 140% of stall speed during straight approach or climb out.

(c) At least 120% of stall speed over threshold and ready for touchdown.

7. NAVIGATION — Plan ahead so that you

(a) Reach destination one hour before sunset unless qualified and prepared for night flight.

(b) Never operate at an altitude less than 500 feet above the highest obstruction (2000 feet in mountain area) except on straight climb from take-off or straight in approach to landing.

(c) Predetermine ETA over all check points. If lost, never deviate from original course until orientated. Always hold chart so plotted course coincides with flight path.

(d) Divert to nearest airport if periodic fuel check indicates you won't have 45 minutes reserve at destination.

8. TAKE-OFF OR LANDING AREA — Plan ahead so that you

(a) Never take-off or land unless on designated airports with known, current runway maintenance.

(b) Restrict operations to runway length equal to airplane manufacturer's published take-off or landing distance, plus 80% safety margin if hard surface, double manual distance if sod, and triple manual distance if wet grass (about same traction as ice.)

(c) Night — Never operate except on well-lighted, night operated airport, and then using steeper approach attitude to clear unlighted obstacles.

9. TAKE-OFF OR LANDING LIMITS — Plan ahead so that you

(a) Always plan touchdown within the first 1/3 of a runway in order to roll to a stop within the second 1/3 having the final 1/3 for spare.

(b) Abort take-off if not solidly "airborne" in first 1/2 of runway.

(c) Abort landing if not solidly "on" in first 1/2 of runway. (First 1/4 if wet grass.)

(d) Never relax control "till the wheels have ceased to roll."

10. WIND LIMITS — Plan ahead so that you

(a) Never attempt taxiing in cross winds or gusts exceeding 50% of stall speed unless outside assistance is available and used — Taxi very slowly when winds exceed 30% of stall speed.

(b) Never attempt take-off or landing when 90° cross surface winds exceed 20% of stall speed or 45° surface winds exceed 30% of stall speed.

(c) Never taxi closer than 1000 feet from "blast" end of powerful airplanes, and then only when headed into remaining blast effect.

(d) Never get close to powerful airplanes on take-off, in air, on landing without allowing time for turbulence to subside — 2 minutes if a jet.

11. PHYSICAL CONDITION — Plan ahead so that you never pilot an airplane when

(a) Having less than "12 hours from bottle to throttle" (24 hours from "big bottle").

(b) Extremely fatigued.

(c) Taking tranquilizing or sleep inducing drugs.

(d) Hypoxic from oversmoking or operating above 10,000 feet (without oxygen).

(e) When emotionally upset.

12. STARTING ENGINE — Plan ahead so that you never, never attempt to hand start an airplane unless qualified person at controls or, in an emergency, unless all wheels are securely blocked and strong, tight, and secure tiedowns are affixed to both wings and tail.

DO'S AND DON'TS FOR SAFE FLIGHT

DO get a weather briefing before taking off on any cross country flight. DON'T assume that the weather will be as it usually is or recently was, or as you wish it to be.

DO seek the advice of others who are better informed about the area's weather flying. Frequently area and route phenomena are known to local pilots or other individuals who may be junior to you in years and overall flying experience. DON'T be too proud to heed this advice.

DO cancel the flight that may be hazardous. DON'T become a "pusher" or you might become a "statistic".

DO have an alternate plan of action if adverse weather is encountered. DO use it while still VFR. DON'T forget the time-honoured 180° method of survival.

DO remember that "sucker holes" are always present to tempt the inexperienced pilot. DON'T be lured into pressing on "just a little farther".

DO reduce airspeed in turbulence. DON'T operate your airplane or your skills at continuous maximum performance.

DO follow regularly traversed routes through mountains or over unfavorable terrain.

DON'T fail to allow yourself a margin for error. Should you be forced to land, be where you can land safely.

DO obtain sufficient altitude before crossing a mountain range. DON'T be caught in the turbulence or downdrafts of ridge crossing.

DO allow sufficient clearance between yourself and the ceiling. DON'T expect all clouds to have flat bases. Often they are quite ragged and irregular with hills and other high ground penetrating their low-hanging portions.

DO have the utmost respect for thunderstorms. They are dangerous! DON'T fly into or near them.

DO fly as a VFR pilot if you are a VFR pilot. DON'T engage in over-the-top flights. The cloud deck may extend farther than you anticipate. Cloud tops may reach altitudes that you and your airplane will not be able to maintain resulting in your becoming involved in instrument flight with the consequent violation of safety and Air Regulations. Also remember you are dependent upon an adequate oxygen intake. DO obtain an instrument rating and fly an IFR equipped airplane if you want to fly above cloud without reference to the ground or horizon.

DO proceed with your alternate plan if you find your destination weather poor. DON'T hold over an airport waiting for ground fog to dissipate. Go to the nearest airport where weather is suitable.

DO remember that poor weather today will probably be good weather tomorrow or the next day.

DO learn to be relaxed yet alert in the cockpit. If the mind and body are tense, fatigue will set in before the flight is terminated and the pilot's ability may become impaired due to such fatigue.

DON'T let anything influence your good judgment.

DON'T get into bad flying habits.

PRINCIPLES OF SAFE LANDING

1. Never land over traffic already lined up on the runway.

2. On approach, line up with the white center line of the runway (if there is one) and stay lined up during approach, touchdown and rollout.

3. In a cross wind landing, the slip method of alignment with the center line of the runway will allow the pilot to determine if the cross wind is too strong. If he can't stay lined up by slipping, he cannot land safely.

4. Never land on a runway if the cross wind component exceeds your self-imposed maximum — or the maximum for the airplane — or the maximum for runway conditions.

5. Always fix a land/no land point on the runway. When you determine you are overshooting, go around.

6. Never land without completing your landing checklist. The item you forgot may be your gear.

7. Never land at an airport if runway conditions are unknown to you.

8. Never land at a **closed** field.

9. Clear for traffic constantly (the final approach is a high potential area for mid-air collision).

10. Be prepared for an aborted landing under emergency type circumstances. **Know the procedure.** Review it briefly while still enroute.

11. Learn to use all the airplane equipment provided for the landing operation. **Know how and when to use flaps.**

12. In a properly executed approach, you will not need full flaps until on final approach.

13. Never get into the habit of dragging in low on final approach. Learn a method of gauging the right approach angle. Conversely, don't develop the habit of diving on the airport. Pilots who do this may end up overshooting.

14. Review approach/landing type accidents. Learn from the mistakes of others. Learning about accidents first-hand is too costly.

15. Recurrent dual instruction and practice provide the only known ways of staying proficient. **Stay proficient.**

16. When runway length is marginal and runway surface conditions and temperature are factors and when landing at high elevations, compute density altitude.

17. At a controlled field, make initial contact 15 miles out.

18. When landing at a field lacking communication, transmit your position blind. Another pilot may be arriving or departing at the same field.

19. When landing VFR at field with one or more instrument approaches, keep your approach path well clear of the instrument approach radio aids. These aids act as funnels for all landing traffic and have a high mid-air collision potential.

PRINCIPLES OF SAFE TAKE-OFF

1. Always use a checklist and always complete the checklist prior to take-off.

2. Review the emergency checklist prior to take-off. You may need the emergency procedure sooner than you think!

3. Always clear area for traffic. Don't take off if you must hurry to avoid traffic.

4. Never take off until you have fully advised the tower, Unicom, etc., of your proposed operation. Don't keep it a secret. If no communication on field, transmit blind your departure runway, turn after take-off, and direction of flight.

5. Always have an abort point on runway selected — and use it if all systems are not "GO" at that point.

6. Don't take off at a closed field.

7. Don't attempt to take off if you don't know runway conditions.

8. Don't take off when the cross wind component exceeds the maximum component you have imposed on yourself — exceeds the maximum for runway conditions.

9. Always use the centre line of the runway. Get the "centre-line" habit.

10. Know the critical "V" speeds for your aircraft: stall speed, dirty and clean, best angle and best rate of climb. Review them prior to take-off.

11. Always compute density altitude when runway length, temperature, field elevation or obstructions ahead create doubt in your mind — and compute it anyway often enough to remember how to do it!

12. For multi-engine aircraft all of the above apply as well as the "V" speeds and performance limits of single engine operation.

13. On cross wind take-offs start take-off roll with ailerons fully deflected in proper direction — then decrease deflection as speed builds.

14. Never become airborne, in a cross wind especially, until the aileron controls are effective.

15. Never take off over gross weight or out of C.G.

16. Never take off with an unresolved problem — either with yourself or the aircraft.

17. During take-off devote full attention to the take-off.

18. With retractable gear always have a positive climb indication before retracting gear.

19. Even when VFR , don't take off until your radio gear is set up. It is much easier to do this on the ground than in the air, especially if an emergency comes along.

20. Even when VFR, if you are at a field with an Omnitest and you are going cross-country make a VOR accuracy check. If there is no Omnitest on the field, make the accuracy check in the air as soon as possible.

21. Never take off downwind unless special conditions dictate.

22. Review take-off accidents for your type aircraft.

23. Periodic practice and recurrent dual instruction are the **ONLY** ways to make sure you are **current** — **proficient** — and **safe.**

24. Never exceed the maximum recommended flap setting for take-off for your aircraft.

Experiments carried out by government testing agencies and by airplane manufacturers have proved conclusively that shoulder harnesses provide much more protection than do seat belts. In fact, it is conjectured that had shoulder harnesses been worn, quite a number of victims of airplane accidents would not have been killed.

When seat belts only are worn, the hips become a pivot point. When the airplane decelerates suddenly, the upper body swings like a pendulum from the hips. The head strikes the control panel or windshield suffering serious and often fatal injury. Properly installed shoulder harness will restrain the whole upper torso and prevent this type of head injury.

Examination Guide . . .

The specimen examination questions which appear in this Chapter are based on both the Private and Commercial Pilot Examination Guides. They are designed to assist you in preparing for your own examination.

It cannot be too strongly emphasized that they are **Sample Questions Only,** not the **actual questions** which you will be called upon to answer—*so do not attempt to memorize the answers.* The questions are offered merely as a guide to the subject matter on which they are based. Study that subject matter until you know it sufficiently well to be prepared to answer any question of a similar nature which could possibly be constructed on an examination paper.

Always read the statement first. Be sure you understand what it means. Decide the correct answer in your own mind (or plot it if it is a problem)—**before you look at the multiple choice answers.** Then select the answer which most nearly coincides with your own reasoning.

The correct *one* of the *four* multiple choice answers will be found in "Answers To The Questions", following the Questions. Mark your selection of the correct answer before you consult the table.

Do not be discouraged if your answer does not *exactly* agree with the one which appears in this manual. Every effort is made to keep this publication completely up-to-date by constant revision, but changes occur so fast that it is difficult to keep pace with them all.

Air Regulations and Air Traffic Rules are also subject to endless change. No attempt has been made in this manual to reproduce these regulations in their entirety although some of the regulations have been outlined in the Section **Rules of the Air** and in the Chapter **Aeronautical Facilities.** It is important for a student pilot to study the Air Regulations and Air Navigation Orders with special reference to the following:

AIR REGULATIONS — Definitions: 101 — Aircraft Registration: 200, 204(I), 207, (C) 220, 221 — Aircraft Airworthiness: 210, 211, 217 (C) 219 — Aerodromes: 309, 313 — Personnel Licensing: 400, 408 (P) 407 — Rules of the Air: 501 thru 538 — VFR: 539 thru 543 — IFR: (C) 544, 545, (P) 546 — Lights and Signals: (P) 557 thru 562, (C) 556 thru 561 — Commercial Air Services: (C) 700 thru 704 — Miscellaneous Provisions: 800 thru 819 — Certificates, Licenses, Manuals, Logs and Records: 821 thru 824 — Accidents and Boards of Inquiry: 826 thru 829.

AIR NAVIGATION ORDERS — Aircraft Seats, Safety Belts and Harness: Series II No. 2 — Airworthiness Certification: Series II, No. 4 — Flying Control Locks: (C) Series II, No. 5 — Flight Instruments and Equipment for Night Flying: Series II, No. 6 — Life Saving Equipment: Series II, No. 8 — Aerodromes, Unlicensed, Markings: (C) Series III, No. 1 — Privileges, Pilots' Licenses: Series IV (P) No. 2, (C) No. 3 — Special VFR Flight: Series V, No. 1 — Cruising Altitudes: Series V, No. 2 — Weather Minima for VFR Flight: Series V, No. 3 — Flight Plans and Notifications: Series V, No. 4 — Distress, Urgency and Safety Signals: Series V, No. 6 — Visual Ground Signals: Series V, No. 7 — Flight Precautions in Sparsely Settled Areas: Series V, No. 12 — Security Control of Air Traffic: Series V, No. 14 — Block Airspace: Series V, No. 15 — Altimeter Setting Procedures: Series V, No. 16.

FLIGHT INFORMATION MANUAL
INFORMATION CIRCULARS
NOTAMS

In addition to the knowledge of radio aids required to obtain either a Private or Commercial Pilot's Licence, a Radio Operator's Licence is required in Canada to operate an aircraft radio transmitter. The examination for the licence consists of a few simple questions to ensure that you understand how to operate receiving and transmitting equipment, that you know the regulations applicable to radiotelephone communications and procedures, and that you know the radio regulations relating to Distress, Urgency and Safety. You are not required to know Morse code or to understand electronic circuits.

CANADIAN EXAMINATIONS

The written examination for a Private Pilot's License in Canada consists of a single paper of 100 questions made up of approximately 25 questions on each of the following subjects: Air Regulations . . . Airmanship (which includes Theory of Flight, Engines, Airframes and general Airmanship) . . . Navigation (which includes airways and cross country procedure) . . . Meteorology.

The Commercial Pilot's examination consists of 3 papers totalling 210 questions grouped as follows: Air Regulations and Air Traffic Procedures . . . Airmanship and Meteorology . . . Flight Planning, Navigation and Radio Aids.

The examination for Block Airspace Endorsement consists of 50 questions in the form of a simulated Controlled VFR cross country flight. The questions are prepared to test your knowledge of flight planning, time estimates, chart reading, reporting points, radio frequencies enroute, clearances, emergency procedure (radio failure) etc.

STUDY MATERIAL

In addition to your text, the Air Regulations and Air Navigation Orders, there are several booklets that are very helpful in preparing for the written pilot examination.

Sample Examination for Private Pilot License. A 22 page booklet containing 100 questions typical of those found in current DOT examinations. Because this booklet is prepared by the authorities who set the civil pilot examinations, it is a good guide to a candidate preparing to sit for an examination.

Study and Reference Guide for Private Pilot or for **Commercial Pilot Licence.** A complete syllabus of Canadian pilot examination requirements. Outlines the subject matter and degree of knowledge required to pass the DOT examinations in the following subjects: Air Regulations, Air Traffic Rules and Procedures, Navigation, Meteorology, Aerodynamics and Theory of Flight, Engines and Airframes, and General Airmanship.

Study Guide for Private Pilots. A collection of about 600 questions relating to all subjects on which an applicant for a Private License may expect to be examined.

These publications are available from the Department of Transport, Ottawa, Canada.

The following publication, while not a "must" for examination requirements, contains extremely valuable information for both VFR and IFR operations, and should be in the possession of all Commercial and Transport Pilots in Canada.

Canada Air Pilot. Published in two volumes, East and West of Winnipeg respectively. Contains complete and detailed data on all aerodromes, seaplane bases, customs airports, radio aids (VOR and LF/MF), airways, radio stations, beacons, broadcasting stations, fan markers, radio frequency bands, instrument approach and landing procedures, D/F procedures, ADIZ, SIZ, and mountain regions. Aerodrome Charts show airport runways, radio aids, instrument landing procedures, field data, ground facilities, etc.

The above publication is obtainable from the Department of Energy, Mines and Resources, Ottawa, Ontario.

Airplane Flight Manual

Specifications and Limitations

Engine: Do not exceed 2600 rpm. manifold pressure—normal operating range 15 to 24 inches Hg.

Fuel: Use 100/130 (low lead) minimum octane gasoline.

Usable capacity 40 Imp. gals. (20 gals. in left tank and 20 gals. in right tank.)

Average fuel consumption 10 gals. per hour, cruising.

Airspeed:

Never exceed	185 mph (160 kts)
Caution range	140-185 mph (122-160 kts)
Cruise (V_{NO})	140 mph (122 kts)
Maneuvering	125 mph (109 kts)
Maximum, flaps down	100 mph (87 kts)

Weight:

Basic weight as equipped	1625 lb.
Maximum gross weight	2550 lb.

Oil:

2 Imp. gals. in engine sump.

COMPASS CORRECTION CARD						
For	0	30	60	90	120	150
Steer	0	29	58	86	115	146
For	180	210	240	270	300	330
Steer	179	212	244	276	304	332

Use nearest value. Do not interpolate.

STALLING SPEED

	Condition	Angle of Bank Degrees			
		0	20°	40°	60°
No stall warning is evident MPH/KTS IAS	Power off: flaps up	59/51	61/53	67/58	83/72
	Power off: flaps down	55/48	57/50	67/58	78/68
	Power on: flaps up	53/46	55/48	60/52	75/65
	Power on: flaps down	50/43	52/45	57/49	70/61

LANDING DISTANCE

	Altitude	Outside Air Temperature					
		– 20°C	– 8°C	4°C	16°C	28°C	40°C
Flaps Down ★ Landing Distance (Feet) over a 50 ft. obstacle at 74 mph (64 kts) IAS approach. (Landing Roll 45% of distance shown).	Sea Level	1590	1650	1710	1765	1820	1870
	2000 Feet	1700	1755	1815	1820	1925	1975
	4000 Feet	1795	1860	1920	1980	2030	2085
	6000 Feet	1905	1965	2030	2085	2140	2190
	7000 Feet	1960	2020	2080	2130	2195	2245

TAKE-OFF DISTANCE

	Altitude	Distance					
Flaps Up ★ T/O Distance (Feet) to clear 50 ft. obstacle at 80 mph (70 kts) (Ground run 40% of distance shown).	Sea Level	1370	1480	1590	1700	1810	1920
	2000 Feet	1670	1790	1920	1950	2190	2340
	4000 Feet	2000	2150	2290	2450	2610	2800
	6000 Feet	2390	2560	2740	2940	3140	3380
	7000 Feet	2740	2840	3050	3280	3510	3770

CLIMB

	Best Climb Speed	Rate-of-climb Ft/Min.					
Flaps Up MPH/KTS IAS	100/87 Sea Level	815	790	765	740	715	690
	98/85 2000 Feet	715	690	670	640	620	595
	96/83 4000 Feet	620	595	570	545	520	495
	94/82 6000 Feet	525	495	470	450	425	395
	93/81 7000 Feet	475	450	420	395	370	345
	91/79 9000 Feet	380	360	330	300	290	250

★ Landing and take-off correction: Reduce distances by approximately 10 percent for each 6 mph (5 kts.) windspeed.

SAMPLE QUESTIONS

1. You are flying at night, off airways, at 3000 feet, and observe the white (or red or white flashing) light of an airplane at approximately your altitude and in your immediate vicinity. If there is a possibility of collision, Regulations require that:

(1) The other pilot alter course to the right.
(2) The other pilot alter course to the left.
(3) You alter course to the right.
(4) You alter course to the left.

2. You are flying an airplane outside of a Control Area on a cross-country flight at an altitude of more than 3500 ft. but below 18000 ft. Your Magnetic Track is 155°. Flight visibility is 2-1/2 miles. Your altitude should be:

(1) Odd thousands.
(2) Even thousands plus 500 ft.
(3) Even thousands.
(4) Assigned to you by ATC.

3. A flashing white light from the control tower to an airplane taxiing or about to take-off means:

(1) Clear the runway.
(2) Delay your take-off.
(3) Return to the ramp or hangar.
(4) Be on the alert for hazardous conditions.

4. An airplane flying at night must display on its right, or starboard wing tip the following light:

(1) A red light visible for 5 miles.
(2) A white light visible for 3 miles.
(3) A flashing green light visible for 3 miles.
(4) A green light visible for 5 miles.

5. An airplane has an engine on fire over a remote area. What radiotelephony call-up signal would the pilot transmit three times:

(1) Mayday.
(2) Pan.
(3) Urgent.
(4) S.O.S.

6. An area in which air traffic control extends upwards *from a specified height above the surface* is called:

(1) A control zone.
(2) A restricted area.
(3) A flight information region.
(4) A control area.

7. You are flying off airways and observe an airplane on your left at approximately your altitude on a converging course which will intercept your track. Who has the right-of-way:

(1) The airplane on your left.
(2) You, because you are on his right.
(3) The airplane at the lower altitude.
(4) The airplane with the greater speed.

8. You know that an aircraft in distress has the right-of-way over all other traffic.

(1) Except an airplane towing a glider.
(2) Except an aircraft on final approach.
(3) Except an aircraft that is approaching.
(4) In all cases.

9. When on final approach for landing, the right-of-way is normally given to:

(1) Faster airplanes.
(2) Slower airplanes.
(3) Airplanes at higher altitude.
(4) Airplanes at lower altitude.

10. The pilot of a fixed wing airplane taking off on a VFR flight must have sufficient fuel to complete the flight with forecast weather conditions, plus reserve fuel for:

(1) Climb to cruising altitude.
(2) 1 hour at normal cruise speed.
(3) 45 minutes at normal cruise speed.
(4) 100 miles diversion to an alternate airport.

11. When a VFR Flight Notification has been filed with the appropriate ATC unit, the pilot in command shall report his arrival within:

(1) 30 minutes after landing.
(2) 1 hour after landing.
(3) 12 hours after landing.
(4) 24 hours after landing.

12. It is the pilot's responsibility to ascertain that certain certificates and documents are aboard the airplane and appropriately displayed. These required documents include:

(1) Registration certificate, Flight Manual, and current airworthiness certificate.

(2) Current airworthiness certificate, operations limitations (Form 309) and Airplane Flight Manual.

(3) Certificate of registration, certificate of airworthiness, journey log books, radio equipment license, license or permit for each crew member.

(4) Airplane operating limitations set forth in a Flight Manual, on placards, listings or markings, current airworthiness certificate, registration certificate.

13. An Air Traffic Control "Instruction".

(1) is the same as an Air Traffic Control "Clearance".

(2) must be compiled with when received by the pilot to whom it is directed unless he considers it unsafe to do so.

(3) must be "read-back" in full to the controller and confirmed before becoming effective.

(4) is in effect "advice" provided by ATC and does not require acceptance or formal acknowledgement by the pilot concerned.

14. When in VFR flight in the Northern Domestic Airspace, the altimeter should be set to ________ and the direction of flight should be determined by ____________ track calculations.

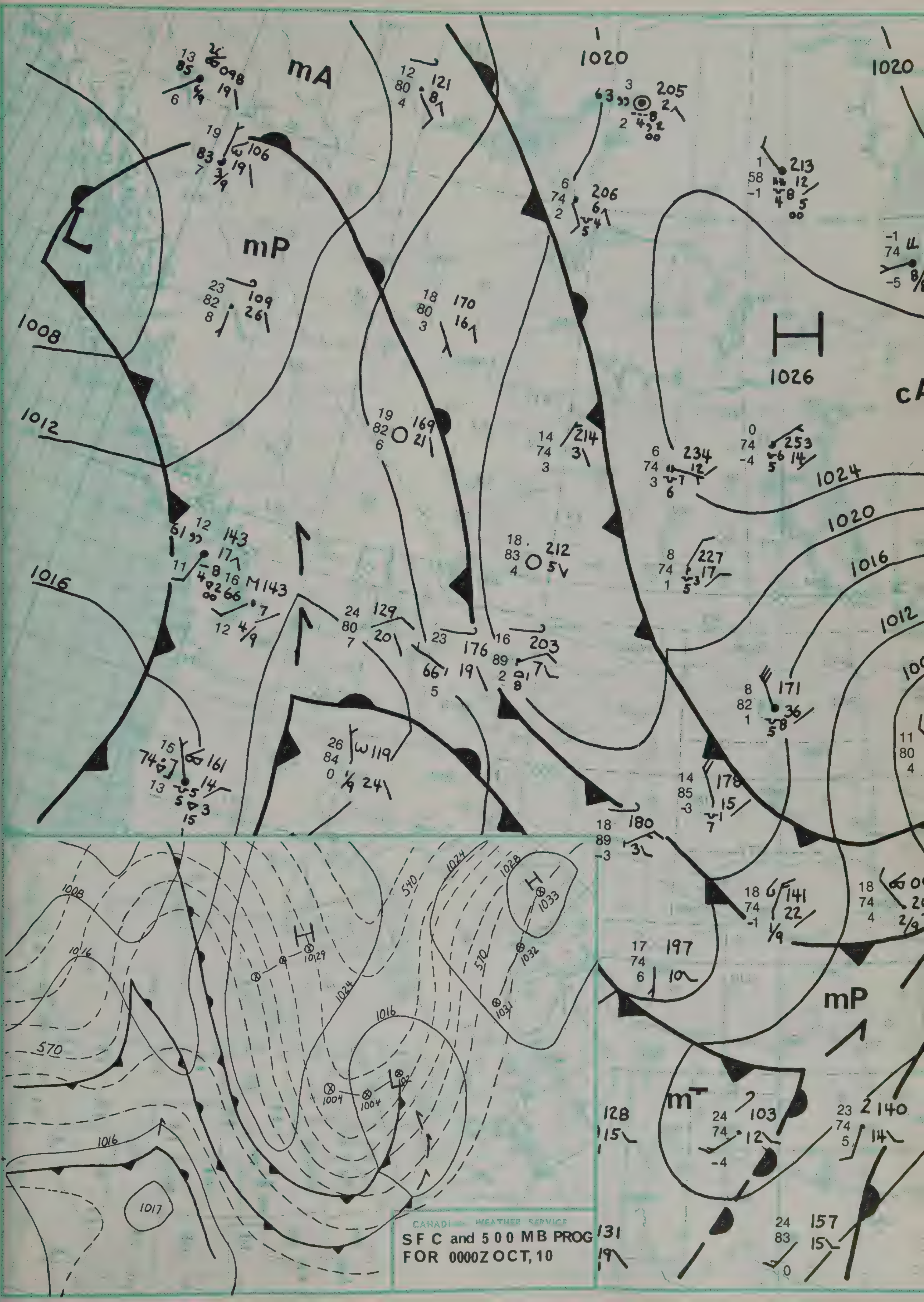
(1) the current altimeter setting of the nearest station along the route of flight — true.
(2) 29.92" Hg — magnetic.
(3) the current altimeter setting of the nearest station along the route of flight — magnetic.
(4) 29.92" Hg — true.

15. Your airplane is equipped with 2-way radio. The weather conditions are below the minima for flight in a Control Zone. You request Special VFR clearance to land at the airport. The minimum ceilings and visibility for Special VFR are:

(1) Ceiling of 800 feet and 1 mile visibility.
(2) Ceiling of 500 feet and 2 miles visibility.
(3) Ceiling of 500 feet and 3 miles visibility.
(4) No minima are established. Clearance from the Control Tower only is required.

16. At high altitude, a pilot is susceptible to hypoxia. Hypoxia is:

(1) Excess carbon monoxide in the hemoglobin.
(2) Lack of sufficient oxygen in the body cells.
(3) Imbalance of oxygen and carbon dioxide in the body system.
(4) Spatial disorientation.



CANADIAN WEATHER SERVICE
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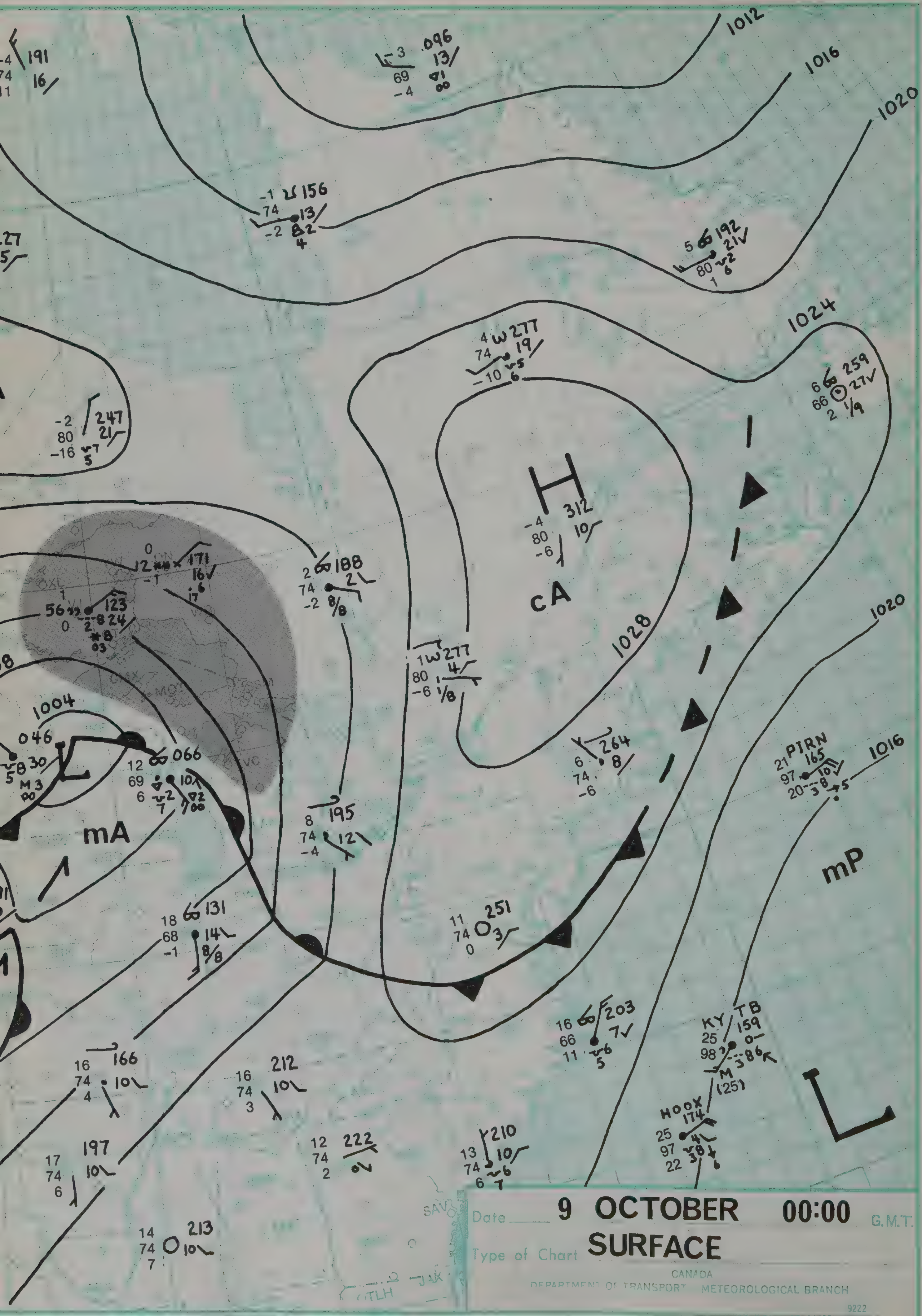


Date 9 OCTOBER 00:00 G.M.T.

Type of Chart SURFACE

CANADA
DEPARTMENT OF TRANSPORT METEOROLOGICAL BRANCH

9222

17. To prevent hypoxia, a pilot should:
    (1) Use oxygen above 5000 feet ASL during daytime.
    (2) Breathe into a paper bag.
    (3) Use oxygen above 5000 feet at night.
    (4) Open the windows and air vents on the airplane.

18. After receiving a local or general dental or other anaesthetic, a pilot should allow hours to elapse before flying:
    (1) 48 (3) 72
    (2) 24 (4) 12

19. One alcoholic drink taken at 5000 feet as compared to the same drink taken at sea level:
    (1) has a lesser effect.
    (2) has a greater effect.
    (3) has no appreciable difference in effect.
    (4) causes flicker vertigo.

20. The motion of an airplane about its normal axis is known as:
    (1) Yawing. (3) Rolling.
    (2) Looping. (4) Pitching.

21. The performance of an airplane is greatly affected by the wing loading. This is a value which is:
    (1) Ratio of the wing area to horsepower.
    (2) Total load the wing will carry.
    (3) Gross weight of the airplane divided by the wing area.
    (4) Gross weight divided by the span.

22. If a thin coating of frost or light snow has formed on the wings of an airplane, the take-off should not be attempted until it has been removed because:
    (1) The coating will disturb the airflow over the wings and destroy some of the lifting capacity.
    (2) The added weight overloads the airplane.
    (3) The covering is cold and brittle.
    (4) The cold air has contracted the covering of the wings, thus changing the airfoil section.

23. The stalling speed of an airplane, when flying upwind as compared to downwind:
    (1) Would differ by an amount equal to the speed of the wind.
    (2) Is the same.
    (3) Is less when flying downwind.
    (4) Is less when flying upwind.

24. Which of the following speeds would be affected by a change in the speed and direction of the wind:
    (1) The true airspeed.
    (2) The indicated airspeed.
    (3) The groundspeed.
    (4) The speed of sound.

25. The five principal factors which affect the magnitude of lift and drag of an airplane wing are:
    (1) Angle of attack — gross weight — lift coefficient — shape of the airfoil — wind velocity.
    (2) Angle of attack — shape of the airfoil — wing area — airspeed — air density.
    (3) Angle of attack — shape of the airfoil — aspect ratio — coefficient of lift — gross weight.
    (4) Angle of attack — thrust — gross weight — airspeed — air density.

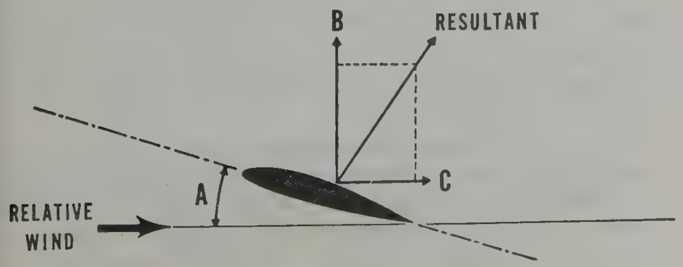


Fig. 26.

26. Referring to Fig. 26, the acute angle "A" may be described as the angle of:
    (1) Incidence. (3) Attack.
    (2) Camber. (4) Dihedral.

27. In level flight at a constant airspeed:
    (1) Thrust exceeds drag.
    (2) Lift exceeds the weight of the airplane.
    (3) Lift equals weight.
    (4) Thrust exceeds gravity.

28. Suppose your airplane stalls at 50 kts. in a 30° banked turn. In a 60° banked turn, the stalling speed would:
    (1) Increase. (3) Be the same.
    (2) Decrease. (4) Double.

29. "Full rich" mixture (in the case of an engine with manual mixture control) would *normally* be used:
    (1) At high altitude.
    (2) For maximum cruise speed.
    (3) To increase the head temperature.
    (4) On take-off.

30. If during a flight at normal cruising speed, one magneto of a "dual ignition" system failed completely, it would normally cause:
    (1) A loss of approximately 75 rpm.
    (2) The engine to overheat.
    (3) Excessive vibration of the engine.
    (4) Considerable extra load to be placed on the other magneto.

31. What would cause a carburetor to flood:
    (1) Excess fuel in the gas tank.
    (2) Turning the propeller over too fast.
    (3) A punctured float in the carburetor.
    (4) A frozen air vent in the fuel tank.

32. The volume of the cylinder at the bottom of the compression stroke compared to the volume at the top of the stroke is called:
    (1) The mean effective pressure.
    (2) The volumetric efficiency.
    (3) The piston displacement.
    (4) The compression ratio.

33. One of the principal advantages of the fuel injection system is:
    (1) Economy of fuel consumption.
    (2) Improbability of carburetor icing.
    (3) Higher horsepower.
    (4) Better general performance.

34. "Coarse pitch", in reference to a propeller:
    (1) Is used for take-off.
    (2) Also is known as "Increase rpm".
    (3) Is used for cruise.
    (4) Should be selected for landing.

35. What is the most commonly recommended practice for preventing condensation in the fuel tanks.
    (1) Drain a pint of fuel from the tank sumps each night.
    (2) Strain all fuel as it is put in the tanks.
    (3) Fill each fuel tank after every flight.
    (4) Install a quick drain gascolator.

36. You make certain that no less than 100/130 octane gas is used in filling your tanks. Use of gasoline with a lower octane rating may cause:

(1) Rough operation and lower manifold pressure.
(2) Detonation.
(3) Pre-ignition and increased output.
(4) The spark plugs to foul.

37. When a check of the dip stick indicates a need for two quarts of oil, the attendant informs you that he has only detergent-type oil available. This means that:

(1) It should never be used in engines over 125 hp.
(2) It can be used only in engines with suitable filters and flexible oil lines.
(3) It is the latest type of oil and should always be used when available.
(4) The oil contains additives, and should be added to the same type of oil only.

38. Preparatory to an initial run-up of your engine, you position your airplane to take into account the wind which is fairly strong. In this regard it is an important safety practice to:

(1) Face your airplane into wind.
(2) Maneuver your airplane into a cross-wind position.
(3) Place your airplane in a downwind position.
(4) Position your airplane so it will not stir up dust.

39. Before engaging your starter to warm up your engine, your propeller:

(1) Should be pulled through several times in order to build up adequate compression for starting.
(2) Need not be pulled through several times as would be done with an airplane with a starter.
(3) Should be pulled through several times to loosen congealed oil and partially prime engine.
(4) Should not be pulled through because of the danger of a ''kickback''.

40. During your run-up you should check to see that carburetor heat is available. This may best be accomplished by:

(1) Applying carburetor heat at idling rpm and checking the tachometer for a drop in rpm.
(2) Visually checking mechanical action of the carburetor heater prior to starting the engine.
(3) Applying carburetor heat during take-off and checking the tachometer for a drop in rpm.
(4) Applying carburetor heat at magneto run-up rpm and checking the tachometer for a drop in rpm.

41. In making the magneto check, you should always:

(1) Make the check at full throttle.
(2) Move the switch from BOTH to RIGHT, to BOTH, to LEFT, and back to BOTH.
(3) Move the switch from BOTH to LEFT, to RIGHT, and back to BOTH.
(4) Move the switch from BOTH to RIGHT, to LEFT, and back to BOTH.

42. You are flying in clear still air. The relative humidity is fairly high. The outside air temperature is 20°C. With these weather conditions it might be possible to encounter:

(1) Precipitation static.
(2) Clear air turbulence.
(3) Carburetor icing.
(4) Clear ice.

43. If carburetor ice is present, the restriction to airflow frequently causes a richer mixture and some loss of power. Application of carburetor heat will likely cause a further *immediate* loss of power. In this case you should:

(1) Leave full heat applied until all ice is dissipated.
(2) Turn carburetor heat off and adjust mixture control to obtain maximum rpm.
(3) Decrease the amount of carburetor heat until rpm increases.
(4) Turn carburetor heat off and open throttle to obtain desired power.

44. If your airplane has a maximum angle of climb at a speed of 94 mph (82 kts.) but the manufacturer's manual recommends climbing at 100 mph (87 kts.) the most probable reason for the higher recommended airspeed would be:

(1) To obtain better visiblity with the nose lowered.
(2) To obtain better cooling of the engine.
(3) Because the head temperature runs higher at the higher airspeed.
(4) Danger of ''stalling out'' in a climb at the lower airspeed.

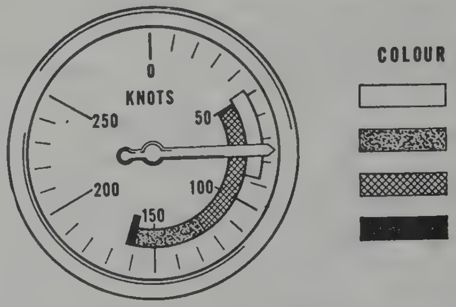


Fig. 45.

Listed below are eight calibrated airspeed limitations and ranges depicted by the airspeed indicator illustrated in Fig. 45.

VNE — Never exceed speed.
VSO — Power-off stall with gear and flaps ''landing'' (down)
VSL — Power-off stall with gear and flaps ''clean'' (up)
VNO — Max. structural cruise (or normal operating limit speed)
VFE — Max. flaps down speed,
Flap operating range.
Normal operating range.
Caution range.

45. By reference to the airspeed indicator illustrated in Fig. 45 you determine that VNO is:

(1) The upper limit of the white arc.
(2) 38 kts. less than VNE.
(3) The upper limit of the yellow arc.
(4) 140 kts. (the mid point of the yellow arc)

COMMENTS: VNE, the never exceed speed, is the red line (160 kts.). VNO, the maximum structural cruise speed, is the upper limit of the green arc, (122 kts.). Answer (2) — 38 kts. (160 − 122 = 38) is therefore correct.

46. The speed recommended for power approaches to short field landings is a constant airspeed not to exceed 1.3 times VSO. Referring to the airspeed indicator in Fig. 45, what should this speed be:

(1) 62 kts.
(2) 66 kts.
(3) 62 mph.
(4) 71 kts.

COMMENTS: VSO, the power-off stalling speed with flaps and gear down, is the lower limit of the white arc, 48 kts. 48 × 1.3 = 62.

47. VA — the design **Maneuvering Speed**, is not indicated on the airspeed indicator in Fig. 45. (It can normally be found in the Airplane Flight Manual or on a placard in the cockpit). This airspeed is important because it is the recommended maximum speed to be used when:

(1) Flying the traffic pattern.

(2) Maneuvering with both the landing gear and wing flaps extended.
(3) Flying in extremely rough air or severe turbulence.
(4) Maximum range (miles per lb. of fuel) is desired.

48. Of the four altimeters illustrated in Fig. 48, select the one that indicates an altitude of 880 feet.

(1) W.	(3) Y.
(2) X.	(4) Z.

COMMENTS: The altitudes indicated are as follows: W — 880 ft. X — 8,800 ft. Y — 18,800 ft. Z — 7,800 ft.

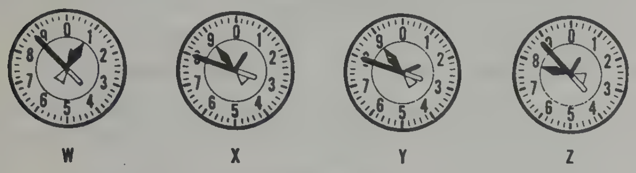
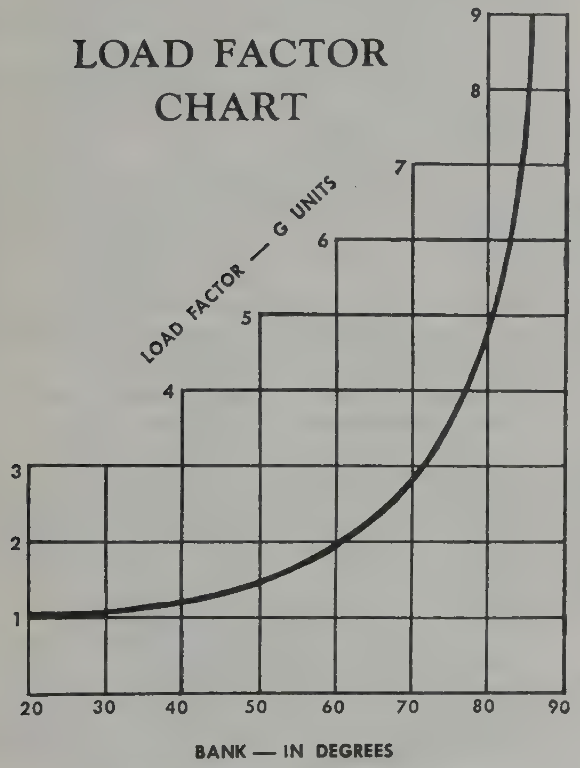


Fig. 48.

49. Referring to the Load Factor Chart, if the maximum flight load factor is 3.8, what is the maximum bank at constant altitude and at maximum gross weight which could be made without exceeding this load factor:

(1) About 67°	(3) Less than 50°
(2) About 76°	(4) Not over 76g's



Load factors produced at varying degrees of bank at constant altitude.

Fig. 49.

50. Referring to the Load Factor Chart, you learn that in a 70° bank you would impose a load factor which, under certain circumstances could prove dangerous. (1 g represents the total weight of the airplane.) In "g" units, the load factor so imposed would be:

(1) More than 3 g's	(3) 2 g's
(2) Almost 3 g's	(4) 6 g's

51. Two of the most important factors which affect the performance of an airplane are temperature and altitude. Assume that you will take-off under the following conditions:

Airport—5000 feet Above Sea Level.
Temperature—28°C.
Airspeed—80 mph (70 kts.).

You take-off directly into a surface wind of 12 mph (10 kts.). With flaps up, your take-off to clear a 50 ft. obstacle will be approximately:

(1) 2875 feet.	(3) 2300 feet.
(2) 2610 feet.	(4) 3140 feet.

COMMENTS: Refer to the **Airplane Flight Manual.** By interpolation, the take-off distance with a temperature of 28°C at 5000 ft. is the mean of the distances at 4000 ft. and 6000 ft., in other words $\frac{2610 + 3140}{2} = 2875$ ft.

With a 12 mph (10 kts.) wind, this distance is reduced by 575 ft. (20% of 2875) = 2875 ft. less 575 ft. = 2300 ft.

52. In the example given in the previous question your "ground run" will be approximately:

(1) 920 ft.	(3) 1044 ft.
(2) 1150 ft.	(4) 1380 ft.

COMMENTS: The **Airplane Flight Manual** states that the ground run is 40% of the total distance. 40% of 2300 = 920 feet.

53. Referring to Fig. 53, and assuming that all the airplanes are making co-ordinated turns, which of the following statements is correct:

(1) Airplane B's rate of turn and radius of turn is the same as airplanes A and C.
(2) Airplanes A, B and C have the same rate of turn, but airplane C has the largest radius of turn.
(3) Airplane A has the greatest rate and smallest radius of turn.
(4) Airplane C has the greatest rate and largest radius of turn.

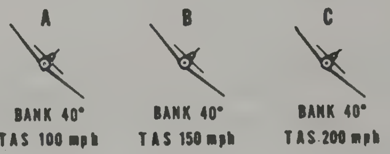


Fig. 53.

54. Since the surface wind is gusting, causing turbulence as you approach to land, it is important to:

(1) Always use full flaps.
(2) Land as slowly as possible.
(3) Maintain the same airspeed you would in smooth air.
(4) Carry a little excess airspeed to assure positive control.

55. In comparison with a take-off and climb made under calm conditions, in climbing an airplane into wind you should recognize that one of the following conditions exists:

(1) The angle of climb is increased.
(2) The rate of climb is increased.
(3) A lower angle of attack is normally employed.
(4) Increased power is normally used.

56. If the plane is improperly loaded and the aft C.G. limit is exceeded to any appreciable extent, it will be:

(1) Difficult to put into a stall and spin.
(2) Nose heavy.
(3) Difficult to get off the ground.
(4) Easy to stall and spin, and recovery would be more difficult than under conditions of proper loading.

57. You enter the traffic pattern. In making the approach for your landing, you adjust the propeller to Fine Pitch in order to:

(1) Keep the engine running at reduced speed.
(2) Reduce the length of the landing roll.
(3) Provide maximum thrust if it is necessary to go around again.
(4) Provide a shallower gliding angle.

58. Match the altitude indicator (gyro horizon) and turn-and-bank indicator in Fig. 58 which indicates a *slipping* turn to the *left*.

(1) A-B.
(2) B-C.
(3) C-D.
(4) A-D.

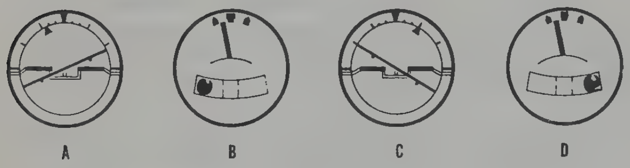


Fig. 58.

59. A front is:

(1) a narrow transition zone between a cyclone and an anticyclone.
(2) a line of thunderstorms.
(3) a narrow transition zone between two air masses.
(4) a mass of layer cloud which is very thick and which covers a wide area.

60. What are the general characteristics of a warm front:

(1) Good flying weather.
(2) Clear but unstable air.
(3) Precipitation, low ceilings and poor visibility.
(4) Clear, good ceilings and stable air.

61. What kind of a front accompanies a line squall:

(1) Cold front.
(2) Warm front.
(3) Stationary front.
(4) Occluded front.

62. Rotation of the earth causes a deflection of winds to the right in the northern hemisphere. The force causing this deflection is called:

(1) Buy Ballots Law.
(2) Pressure gradient.
(3) Convergence.
(4) Coriolis Force.

63. The clouds which appear, in sequence, in advance of an approaching warm front are:

(1) Cirrus, cirrostratus, altostratus and nimbostratus.
(2) Cumulus, cumulonimbus and nimbostratus.
(3) Cirrus, cumulonimbus and nimbostratus.
(4) Altrostratus, cumulus, cumulonimbus and nimbostratus.

64. In certain circumstances, air at higher altitudes may be warmer than the air below it. This is called:

(1) Convection.
(2) Inversion.
(3) Radiation.
(4) Lapse Rate Reversal.

65. When unsaturated air is forced to rise, the expansion of the rising air causes it to cool. This cooling is called the:

(1) Normal lapse rate and is 1.6°C per 1000 feet.
(2) Unstable lapse rate and is 2°C per 1000 feet.
(3) Dry adiabatic lapse rate and is 3°C per 1000 feet.
(4) Stable lapse rate and is 3°C per 1000 feet.

66. The dissipation of fog is assumed to result from:

(1) An increase in the wind velocity so as to blow the fog away.
(2) Condensation of the suspended water droplets in the fog in the form of rain or dew, thus eliminating the suspended droplets from the atmosphere.
(3) Heating from below from sunlight which filters down through the fog or stratus layer.
(4) Cooling of the air mass with a resulting decrease in the vapor pressure of the air mass.

67. Maximum icing conditions are usually encountered between temperatures of:

(1) 0° to 4°C
(2) 2° to −10°C
(3) 0° to −32°C
(4) −5° to −10°C

68. In the northern hemisphere, continuing drift to the right may indicate that you are approaching an area of low pressure. This will cause an uncorrected altimeter to:

(1) Read too high.
(2) Read too low.
(3) Indicate loss of height.
(4) Gradually decelerate.

69. Some of the hazards associated with thunderstorms are turbulence, lightning, hail, icing. The type of cloud in which these conditions are apt to occur is:

(1) Nimbostratus.
(2) Stratocumulus
(3) Altocumulus.
(4) Cumulonimbus.

70. If you were flying westerly and you encountered a range of mountains which were lying north and south and you attempted to fly through a saddle on a west heading with the wind from the west, you would expect:

(1) To lose altitude rapidly on the west side of the saddle.
(2) To lose altitude rapidly on the east side of the saddle.
(3) To lose altitude rapidly while in the saddle.
(4) To gain altitude rapidly on the east side of the saddle.

COMMENTS: This question refers to the phenomenon known as The Mountain Wave.

71. If you were landing at an airport that had a south wind at 2000 ft. altitude, you could expect the surface wind to be from:

(1) South.
(2) West.
(3) East.
(4) Southeast.

72. The movement of air outward from areas of high pressure and inward towards areas of low pressure is called wind. In a low pressure area, the surface wind blows:

(1) Clockwise outward.
(2) Anticlockwise inward.
(3) From east to west.
(4) Clockwise inward.

73. The moisture content of the air definitely affects the ceiling and visibility. The temperature and *dewpoint* relationship presented in the hourly sequence report is highly significant to the pilot because it may represent a critical condition of the air. Dewpoint is:

(1) A figure representing the relative humidity.
(2) The temperature to which air must be cooled at constant pressure to become saturated.
(3) The amount of moisture present in the air.
(4) The temperature to which air must be warmed to become saturated.

74. The surface weather map (inset) indicates that at map time:

(1) A cold front, backed by a maritime arctic air mass extended through the New England States.
(2) A warm front composed of maritime tropical air had moved in from the Pacific Coast and was causing precipitation generally over Utah and Arizona.
(3) The cold front lying off the Eastern Atlantic seaboard is weakening and is likely to disappear.
(4) Low pressure air was moving in from the Atlantic over Maryland and Virginia, causing clear cooler weather.

75. The principal value of the surface weather map to you as a pilot lies in the fact that such a map enables you to:

(1) Get a broad picture of the weather conditions existing over the area through which you intend to fly.

(2) Forecast the weather conditions at the airport of destination.
(3) Forecast the weather conditions along your intended route.
(4) Plot a course, or track, which will enable you to avoid weather hazards en route.

WEATHER DATA

Terminal Forecasts: The following terminal forecasts were available at the Calgary Weather Office. They were issued at 11:45 GMT and are valid from 1200 GMT to 2400 GMT.

YYC (Calgary) CLR 0215
YQL (Lethbridge) C30 OVC 3625 1600Z 20 SCT C60 BKN 3110
YXH (Medicine Hat) C30 OVC 3620 1700Z 30 SCT C80 BKN 3115G
YQR (Regina) C13 OVC 4TRW- 3125 1800Z 30 SCT C90 BKN 3615G

Hourly Weather Sequence Reports: The following sequences were available at the Calgary Weather Office. They are the weather reports for 1300 GMT.

YYC CLR 15 205/9/2/3620/012
YQL M27 OVC 8 173/7/2/3610/003
YXH 12 SCT E25 OVC 10 132/10/6/0222G30/992
YQR M13 BKN 85 OVC 4RW- 095/9/8/3120G26/976

Winds Aloft Forecast: The available forecast of winds at Calgary is valid from 1000 GMT to 2200 GMT

	6000	9000	12000	15000	18000
YYC	0215	3520	2930	2935	2840

76. Weather information is of prime concern to the pilot in preflight planning. Terminal forecasts and teletype sequence reports are especially helpful. Issuance and period covered for these reports are as follows:

(1) Terminal forecasts are issued 4 times daily and usually cover a period of 12 hours. Sequence reports are issued every hour.
(2) Terminal forecasts are issued twice daily and usually cover a period of 48 hours. Sequence reports are issued every hour.
(3) Terminal forecasts are issued 4 times daily and usually cover a period of 12 hours. Sequence reports are issued every 30 minutes.
(4) Terminal forecasts are issued 4 times daily and usually cover a period of 6 hours. Sequence reports are issued every hour, approximately on the half-hour and are broadcast by aeradio stations.

77. Your principal source of information for weather conditions which exist *between* reporting stations is from:

(1) Pilot reports enroute (Pireps) or direct contact with a pilot who has just flown the area.
(2) Control Towers.
(3) Commercial broadcast stations.
(4) The weather sequence report.

78. In the hourly weather sequence reports, cloud heights are reported in hundreds of feet above:

(1) The highest terrain within a radius of 25 miles of the station of observation.
(2) The highest obstruction within 5 miles of the perimeter of the airport.
(3) The surface at the station of observation.
(4) MSL (mean sea level) at the station of observation.

79. At Calgary (YYC) the reported weather is:

(1) Ceiling is unlimited — visibility 15 miles — sea level pressure 1020.5 millibars — temperature 9°C — dewpoint 2°C — wind 360° 20 kts. — altimeter setting 30.12 inches.
(2) Ceiling is zero — visibility 15 miles — sea level pressure 1020.5 millibars — temperature 9°C — dewpoint 2°C — wind 360° 20 kts. — altimeter setting 30.12 inches.
(3) Ceiling unlimited — visibility 15 miles — sea level pressure 1020.5 millibars — temperature 9°C — dewpoint 2°C — Wind 180° 20 kts. — altimeter setting 30.12 inches.
(4) Ceiling unlimited — visibility 15 miles — sea level pressure 1020.5 inches — dewpoint 9°C — temperature 2°C — wind 360° 20 kts. — altimeter setting 30.12 inches.

80. The report of weather and obstructions to vision at Regina (YQR) was:

(1) Moderate rain.
(2) Light rain showers.
(3) Very light freezing rain.
(4) Light snow showers.

81. Winds aloft **forecasts** are available for many stations. These forecasts often prove very helpful in trip planning. Referring to the winds aloft forecast we find that the wind direction and speed at YYC between 10:00 and 22:00 at 7500 feet (by interpolation) would be approximately:

(1) 350° at 20 kts. (3) 030° at 15 kts.
(2) 005° at 18 kts. (4) 040° at 32 kts.

82. World Aeronautical Charts are based on a Lambert Conformal Conic Projection. The following list contains 3 properties characteristic of this projection, and 3 other properties characteristic of a Mercator Projection:

A. Meridians are straight parallel lines, intersecting the parallels (which are also straight, parallel lines) at right angles.
B. Meridians are converging lines, intersecting the parallels (which are concentric arcs of circles) at right angles.
C. A straight line represents a Great Circle.
D. A straight line represents a Rhumb Line.
E. Scale errors are small, hence the scale may be considered constant over a single sheet.
F. Scale varies with latitude and is only constant at the equator, hence distances must be measured on the latitude scale adjacent to the area.

Which of the following includes the 3 items which are characteristic of the Lambert Conformal Conic Projection:

(1) A — C — F. (3) A — D — E.
(2) B — D — F. (4) B — C — E.

83. What does a map scale expressed as 1:1,000,000 mean:

(1) 1 inch = 8 miles.
(2) 1 inch on the map = one millionth of a mile.
(3) 1 mile equals 1,000,000 inches.
(4) 1 inch on the map = 1,000,000 inches on the ground.

84. Magnetic variation is defined as:

(1) Errors in the compass caused by magnetic field associated with metal in the airplane frame and engine.
(2) The difference between the magnetic track and the magnetic heading of the airplane.
(3) The angle between true north and magnetic north at any given point on the earth.
(4) The difference between true track and magnetic track.

85. In the northern hemisphere, if your airplane is on a *northerly heading,* and a turn is made toward the east or west, the compass reading:

(1) Will lag (under register the turn) or indicate a turn in the opposite direction.
(2) Will lead (precede the turn) or indicate a turn in the opposite direction.
(3) Is inversely proportional to the magnetic variation for the particular area.
(4) Will be correct, providing the turn has been perfectly co-ordinated.

86. Complete familiarity with the compass rose is essential to navigation. Which of these statements is true:
(1) The reciprocal of 267° is 117°.
(2) The direction NE is 090°.
(3) To turn right 90° from a heading of 145° would be a turn to 235°.
(4) The reciprocal of 115° is 225°.

87. The following are terms which you, as a pilot, should be familiar with:

A. Isogonic Line. C. Agonic Line.
B. Isobar. D. Isotherm.

Below are the definitions of these terms:

W. A line connecting points of equal pressure on a constant altitude chart.
X. A line on a chart joining all points of zero variation.
Y. A line on a chart joining points of equal variation.
Z. A line on a chart joining places or points having equal temperatures.

Associate the terms with their appropriate definitions:
(1) A-W, B-X, C-Z, D-Y.
(2) A-X, B-W, C-Y, D-Z.
(3) A-Y, B-W, C-X, D-Z.
(4) A-Y, B-Z, C-W, D-X.

88. In the vicinity of the magnetic poles there is an area:
(1) in which all airplanes must be under positive control.
(2) in which the compass in unreliable.
(3) in which you must reset the DG every 3 minutes.
(4) in which the northerly turning error of the compass is more pronounced than usual.

89. An airplane flying VFR along a Victor airway should fly:
(1) On the left hand side of the airway, flying away from the station.
(2) Along the right hand side of the airway, in the twilight zone.
(3) Down the centre line of the airway.
(4) At even altitudes plus 500 eastbound.

90. With the Bearing Selector *set* to 270°, list all the airplane positions (Fig. 90) that would give a TO reading on the TO- FROM Indicator.
(1) G and B (3) F, G and H
(2) A, D and G (4) E, F, G and H

COMMENTS: F, G and H would show TO. E would show neutral. A, B, C, and D would show FROM.

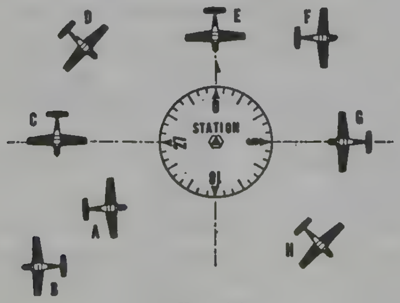


Fig. 90.

91. *Two* of the following four statements are characteristic of VHF equipment:

A. One of the disadvantages of VHF is its susceptibility to atmospheric and precipitation static.
B. VHF is relatively free from atmospheric and precipitation static.
C. Reception distance for usable service is generally based on radio "line of sight".
D. Reception distance remains constant regardless of the altitude.

The statements that correctly reflect characteristics of VHF equipment are items:
(1) A and D. (3) A and C.
(2) B and D. (4) B and C.

92. What is one of the indications you observe when you fly directly over an omnirange station on a preselected course:
(1) The needle will swing through 180°.
(2) The bearing selector will return to 0°.
(3) You will penetrate a cone of silence.
(4) The TO and FROM indication will reverse.

93. For VFR flight, below 10,000 feet, the proper transponder code to select is:
(1) 0600 (3) 7700
(2) 1400 (4) 1200

94. The emergency VHF frequency is:
(1) 122.1 MHz (3) 121.5 MHz
(2) 118.3 MHz (4) 5280 KHz

95. You have a low frequency radio receiver installed in your airplane fitted with a beat frequency oscillator and capable of receiving on C.W. This equipment would enable you to receive signals from:
(1) An omnirange. (3) A vortac station.
(2) A Z marker beacon. (4) A consolan station.

96. How do you determine that drift is present when homing by ADF:
(1) By variation of the ADF when maintaining a constant heading by gyro or magnetic compass.
(2) By variation of the gyro magnetic compass when maintaining a constant heading by ADF.
(3) If the reading on the gyro is higher than the ADF, the drift is to starboard.
(4) When the reading on the magnetic compass and ADF do not agree.

97. What does the needle of the ADF *normally* indicate:
(1) The loop position of maximum signal strength.
(2) The relative bearing of the station.
(3) The relative heading of the airplane.
(4) The magnetic bearing of the radial towards the station.

The following questions concern a typical cross-country flight undertaken by a private pilot.

You are the owner and pilot of a light airplane with the Canadian registration C-FAXZ. Specifications and performance data are contained in the Airplane Flight Manual at the beginning of the chapter.

You plan a flight from Calgary International Airport to Lethbridge Airport, where you will stop over for a few hours. From Lethbridge, you will proceed to Medicine Hat and then to Swift Current and then will return to Calgary. To plan this flight, refer to the map insert at the back of the book.

Two friends will accompany you on the flight.

From the Weather Office, you learn that the weather will be satisfactory for VFR flight along your flight route, although there are some local rain showers and some turbulence at lower levels, and considerable wind and gustiness on the surface at many of the stations in the general area.

Draw lines on your map to represent the True Track between the airports you intend to visit, mark prominent check points along the route, note distances between each. Note communication and navigation facilities available enroute.

You concern yourself with the problem of proper load distribution, observing placard weight limits for the baggage compartment, and maximum load limitation.

98. One passenger weighs 172 lb. and the other 192 lb. Your weight is 179 lb. You have three pieces of luggage weighing 30, 24 and 17 lb. each. With maximum (usable) fuel aboard and oil tank filled, the take-off weight of the airplane would be:

(1) The same as the certified gross weight.
(2) Slightly more than the certified gross weight.
(3) 5 lb. less than the certified gross weight.
(4) 56 lb. less than the certified gross weight.

COMMENTS: The Airplane Flight Manual specifies the basic weight of the airplane as 1625 lb. The loaded weight is therefore as follows:

Basic weight	1625 lb.
2 passengers	364 lb.
3 pieces luggage	71 lb.
Pilot	179 lb.
40 gals. fuel @ 7.2 lb/gal	288 lb.
2 gals. oil @ 9 lb/gal	18 lb.
Take-off weight loaded	2545 lb.

See the Airplane Flight Manual for the certified gross weight for this airplane.

In computing the loaded weight of the plane above, the actual weights of the passengers have been used. If the actual weights are not known, the pilot may assume average weights per person. These were listed in the Section **Weight and Balance.**

99. The total distance you propose to fly is approximately:

(1) 531 s. miles (460 n. miles)
(2) 542 s. miles (471 n. miles)
(3) 627 s. miles (542 n. miles)
(4) 596 s. miles (519 n. miles)

100. If you are able to maintain an **average** groundspeed of 142 mph (123 kts.) during your round robin cross country flight, you will find it necessary to gas at least once. If you maintain a 45 min. fuel reserve during the entire trip and gas only once, it must be done at:

(1) Lethbridge
(2) Swift Current
(3) Medicine Hat
(4) Calgary

COMMENTS: This is a fuel hour problem. Your fuel capacity is 40 Imp. gals. Average fuel consumption is 10 gals. per hour. Your safe fuel hours are therefore (40 ÷ 10) 4 hours less 45 minutes reserve or 3.25 hours.

At an average groundspeed of 142 mph, in 3.25 hours, you will travel (142 × 3.25) 462 miles.

You will therefore have sufficient fuel to reach Swift Current which is 346 miles but not enough to complete the entire trip.

101. The compass heading from Calgary to Lethbridge is:

(1) 131°
(2) 152°
(3) 127°
(4) 306°

COMMENTS: To find compass heading from true heading, apply variation and deviation.

102. You set your sensitive altimeter to the elevation of Calgary Airport which is 3557 feet Above Sea Level. If properly calibrated, your barometric scale should indicate a setting of approximately:

(1) 1020.5 millibars
(2) 30.12 inches
(3) 30.03 inches
(4) 1017.3 millibars

COMMENTS: When the altimeter setting is set on the Barometric Scale, the altimeter will register the altitude of the field Above Sea Level. Conversely, when you set the altitude of the field, 3557 feet, on your altimeter, the Barometric Scale will record the correct altimeter setting. Refer to the last available hourly sequence report for YYC at 1300 GMT.

103. Assuming that the surface wind at Calgary is the same as that reported at 1300 GMT, you will take-off on a runway that is as nearly aligned as possible to the:

(1) South
(2) Southwest
(3) North
(4) Northeast

104. After getting a take-off clearance from the Calgary Tower, you take-off at 10.02 local time. You climb to cruising altitude of 5000 feet MSL. Using a true airspeed of 99 mph (86 kts.) in your climb, which gives a rate-of-climb of 670 ft. per min., you should reach cruising altitude at approximately:

(1) 10:10
(2) 10:04
(3) 10:21
(4) 10:14

COMMENTS: The field elevation at Calgary is 3557 ft. You would therefore have to climb (5000 – 3557) 1443 feet to reach cruising altitude.

105. Some useful landmarks you might pinpoint between Calgary and Lethbridge Airport would be:

(1) The Bow River — the railroad line from Calgary to Lethbridge that passes through the town of Vulcan — the Little Bow River — the Old Man River.
(2) The Bow River — the railroad line from Calgary to Lethbridge that passes through the town of Vulcan — the Little Bow River — the Amber 2 Air Route.
(3) The Bow River — the railroad line from Calgary to Lethbridge that passes through the town of Vulcan — the Little Bow River — the 20° isogonal line.
(4) The Bow River — the railroad line from Calgary to Lethbridge that passes through the town of Vulcan — the Little Bow River — the Saint Mary Reservoir.

106. You climb to cruising altitude of 5000 feet MSL in 2 minutes and at 10:16 you cross the Bow River. At 10:34 you are over the small lake on track near Champion. This time and distance check indicate that your ETA at Lethbridge should be:

(1) 10:45
(2) 11:05
(3) 11:15
(4) 10:54

COMMENTS: The distance from the Bow River to the lake is approximately 44 s. miles (38 n. miles). This took you 18 minutes. You are therefore making good a groundspeed of 147 mph (128 kts.). The distance from your check point to Lethbridge is 48 s. miles (42 n. miles). With a groundspeed of 147 mph, the time to fly 48 s. miles would be approximately 20 minutes (48 ÷ 147 × 60).

107. Your outside (ambient) air temperature gauge indicates approximately 4°C at your cruising altitude of 5000 ft. MSL. Assuming a normal lapse rate, the freezing level for this region should be approximately at:

(1) 7500 ft. MSL
(2) 7500 ft. AGL
(3) 6500 ft. MSL
(4) 2500 ft. AGL

COMMENTS: The temperature at cruising altitude is 4°C. The normal lapse rate is 1.6°C per thousand feet. The freezing level is therefore (4 ÷ 1.6) 2.5 thousand feet higher than cruising altitude.

108. Fifteen miles out, you call Lethbridge Tower to report your position and intentions. The Tower frequency at Lethbridge is:

(1) 248 KHz
(2) 118.3 MHz
(3) 121.5 MHz
(4) 115.7 MHz

109. Lethbridge Tower answers your transmission with the following instruction:

Foxtrot Alpha Xray Zulu — Runway Three Zero — Wind Three Six Zero at One Zero — Altimeter Three Zero Zero Three — Report Five Miles North — Over.

From the preceding message, you know that:

(1) You are cleared to land.
(2) The altimeter setting is Three Zero One Two.
(3) Your downwind magnetic heading will be approximately 120°.
(4) The wind is 14 mph.

110. You land at Lethbridge and after a 2-1/2 hour stop over are ready to leave for Medicine Hat. The true track from Lethbridge Airport to Medicine Hat Airport is:

(1) 254° (3) 164°
(2) 074° (4) 294°

111. The Magnetic Track from Lethbridge to Medicine Hat is:

(1) 144° (3) 094°
(2) 274° (4) 054°

112. You plan to fly the second leg of your trip, Lethbridge to Medicine Hat, at 5000 feet MSL, at a true airspeed of 140 mph (122 kts.). The reported winds are from 010° at 20 knots (23 mph). Your compass heading (see compass correction card) should be:

(1) 044° (3) 060°
(2) 065° (4) 085°

COMMENTS: Your True Track from Lethbridge to Medicine Hat is 074°. Your airspeed is 122 kt. (140 mph.). The wind is from 010° at 20 knots. Find True Heading and Groundspeed as in the Wind Drift Problems. Convert True Heading to Magnetic Heading by applying Variation. Convert Magnetic Heading to Compass Heading by applying Deviation (see compass correction card).

113. You take-off from Lethbridge at 13:15 local time and level off at cruising altitude 5000 ft. MSL. Based on your expected groundspeed (determined in question 112) your ETA at Medicine Hat should be approximately:

(1) 14:05 (3) 13:45
(2) 14:15 (4) 14:00

You land at Medicine Hat and after a short stop over are ready to take-off at 14:30.

114. You take-off from Medicine Hat and decide to use Omninavigation for the next leg of your flight. The VOR frequency of the Medicine Hat Omni is 116.5 MHz. You set the Bearing Selector on your Omni receiver to 061 and head east. When the needle on your cross pointer indicator centres:

(1) Your TO FROM indicator will read FROM.
(2) You will be on a radial 241° from Medicine Hat.
(3) Your TO FROM indicator will read TO.
(4) You will be on a True Bearing 061° from Medicine Hat.

115. You tune in Empress VOR station and get a bearing of 150° TO the station. Since the left right needle on your cross pointer indicator showed you previously to be almost exactly on course, you should now be:

(1) Directly over Bitter Lake.
(2) 70 s. miles from Swift Current.
(3) Directly over Many Island Lake.
(4) 60 s. miles out of Medicine Hat.

116. A little later, you tune your Omni receiver to 117.4 MHz. This is the frequency for the:

(1) Beechy VOR (3) Empress VOR
(2) Swift Current VOR (4) Lumsden VOR

117. The left right needle centres when the bearing selector shows 060° FROM. You are:

(1) On course.
(2) South of your track.
(3) North of your track.
(4) 45 miles from Swift Current.

118. At 15:31 you are over the city of Swift Current. Your average groundspeed for this leg was:

(1) 120 mph (3) 131 mph
(3) 140 mph (4) 128 mph

You land at Swift Current and fill your fuel tanks for the final leg to Calgary.

119. The reported winds are from 020° at 15 knots. With a true airspeed of 140 mph, you estimate your flying time from Swift Current to Calgary to be:

(1) 137 mins. (3) 118 mins.
(3) 125 mins. (4) 105 mins.

COMMENTS: With a true airspeed of 122 knots (140 mph) and wind from 020° at 20 knots, find Groundspeed and True Heading. The distance from Swift Current to Calgary is 244 n. miles (282 s. miles).

120. You take-off from Swift Current at 16:55 and turn on to a Compass Heading of 263°. At 17:40 you see the South Saskatchewan River ahead. You divert slightly off track to the north to avoid the area CYD 202. This is:

(1) A restricted area.
(2) A military flying area.
(3) An alert area.
(4) A danger area.

121. You are cruising along and maintain 6000 ft. MSL. You know that with a power setting of 22 inches on the manifold pressure gauge you should be utilizing 50% power. Several minutes after reading 22 inches on the manifold pressure gauge, you check again and find that your manifold pressure now reads 20 inches. You immediately check your altimeter and find that it still registers 6000 ft. This would indicate that:

(1) The manifold pressure gauge has failed.
(2) You are accumulating carburetor ice and should apply carburetor heat.
(3) You have entered better atmospheric conditions and are now obtaining 50% power with only 20 inches of manifold pressure.
(4) The atmospheric pressure has dropped 2 inches.

122. Some 30 miles from Calgary Airport, you tune to the frequency 114.8 MHz to receive the ATIS information for Calgary Airport. ATIS gives information relating to:

(1) Ceiling, visibility, wind, altimeter setting, runway in use.
(2) Ceiling, wind, altimeter setting, runway in use, traffic density.
(3) Ceiling, visibility, wind, runway in use, landing clearance.
(4) Ceiling, wind, altimeter setting, runway in use, DF steer.

123. From the ATIS information, you learn that the runway in use is Runway Three Four. This runway:

(1) Has a true direction of about 034°.
(2) Has a true direction of about 340°.
(3) Has a magnetic direction of about 340°.
(4) Has a magnetic direction of 034°.

124. You tune to the Tower frequency of 118.7 MHz. When about 15 miles from the airport, you call the Tower, giving your position, advising that you have received the ATIS information, and you request landing instructions.

When the Tower clears you to land, you are notified that the surface wind is quite gusty. In view of this condition, your best landing procedure would be to:

(1) Make a partial-power wheel landing and keep the airplane in a well controlled, tail-high attitude as long as possible.
(2) Make a partial-power stall landing in order to have minimum lift at the time of ground contact.
(3) Land the airplane at a higher than normal landing speed, and bring the tail to the ground as soon as possible.
(4) Land the airplane in a full-stall attitude in order to keep the tail on the ground.

125. After you have landed and turned off the runway in use, the Tower instructs you to switch to Ground Control frequency for taxi instructions. You tune your receiver to:

(1) 121.5 MHz
(2) 120.7 MHz
(3) 121.9 MHz
(4) 121.7 MHz

ANSWERS TO THE QUESTIONS

1. (3)
2. (1)
3. (3)
4. (4)
5. (1)
6. (4)
7. (2)
8. (4)
9. (4)
10. (3)
11. (4)
12. (3)
13. (2)
14. (4)
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16. (2)
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94. (3)
95. (4)
96. (2)
97. (2)
98. (3)
99. (3)
100. (2)
101. (3)
102. (2)
103. (3)
104. (2)
105. (1)
106. (4)
107. (1)
108. (2)
109. (3)
110. (2)
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112. (1)
113. (4)
114. (1)
115. (1)
116. (2)
117. (2)
118. (4)
119. (3)
120. (4)
121. (2)
122. (1)
123. (3)
124. (1)
125. (3)

AIR TRAFFIC CONTROL QUESTIONS

The Department of Transport requires that all persons taking exams to acquire any class of pilot licence must also write an exam on Air Traffic Control Procedures and Pilot/Controller Responsibilities.

Examination candidates will find it to their advantage to be familiar with the following: Air Traffic Control Procedures as they apply to the control of VFR traffic at controlled airports; Air Traffic Procedures at non-controlled airports and aerodromes; Good airmanship practices, with particular reference to the avoidance of wake turbulence; Special VFR regulations; Air Traffic Control Clearances and Instructions.

The following rules and regulations should be reviewed:

AIR REGULATIONS — Part I, Section 101, (2), (8), (9), (11), (12), (13), (14), (28), (35), (56), (65) — Part V, Sections 505, 516, 517, 520, 521, 526, 536, 537, 540, 541, 544, 600, 816, 817.

AIR NAVIGATION ORDERS — Series V, No. 1, 3, 4, 21.

FLIGHT INFORMATION MANUAL — Part 4, Airmanship — Part 6, Air Traffic Control Procedures.

The following 42 questions are typical of those comprising the examination.

1. Light aircraft are particularly susceptible to wing tip vortices that form in the wake of an aircraft. The most severe wake turbulence is produced by:

(1) small aircraft during take-off or landing.
(2) large aircraft during take-off or landing.
(3) small aircraft in cruising flight.
(4) large aircraft in cruising flight.

2. Propeller or jet wash can be a serious hazard to a light aircraft on the ground. When parking for run up behind large aircraft you should:

(1) ensure that your aircraft is cross wind to the propeller or jet wash.
(2) ensure that there is a minimum of 400 feet between your aircraft and the propeller or jet wash.
(3) ensure that your aircraft is accurately lined up behind the centre of the aircraft performing a run up.
(4) use full carburetor heat to reduce ram air effect.

3. You are pilot of a NORDO aircraft approaching an airport, and you do not know if the circuit is left or right hand. You should circle the airport at:

(1) 1000 feet above ground.
(2) 2000 feet above ground.
(3) 1000 feet above MSL.
(4) 2000 feet above MSL.

4. You are on final approach to a controlled airport and the controller clears you to land. You should:

(1) click your microphone button twice in acknowledgement.
(2) transmit a verbal acknowledgement to the tower.
(3) execute a 360° turn to show that you have received the controller's message.
(4) not acknowledge if you are too busy.

5. An ATC clearance or instruction is predicated on known traffic only. Therefore, when accepted by the pilot it:

(1) relieves the pilot of responsibility for traffic avoidance.
(2) relieves ATC of responsibility for traffic separation.
(3) divides responsibility for traffic separation between ATC and the pilot.
(4) does not relieve the pilot of responsibility for traffic avoidance.

6. Which statement is correct and needs careful consideration by the pilot of a light aircraft before accepting a take-off clearance immediately following the arrival or departure of a heavy aircraft:

(1) Wing tip vortices are carried by the ambient wind.
(2) Wing tip vortices have a circular and downward motion when shed.
(3) Wake turbulence exists behind heavy aircraft both when taking off and landing.
(4) All of the above are correct.

7. A pilot accepts a clearance and subsequently finds that all or part of the clearance cannot be complied with. He should:

(1) comply as best he can under the circumstances to carry out the clearance and say nothing to ATC.
(2) comply as best he can under the circumstances and advise ATC as soon as possible.
(3) disregard the clearance.
(4) comply with only the part that suits him.

8. A pilot on a VFR flight has requested Radar Assistance and is flying a radar vector, provided by ATC, to the nearest airport. Ahead, and below is a solid overcast cloud condition.

The responsibility of keeping clear of cloud is:

(1) the sole responsibility of the pilot.

(2) the responsibility of ATC as the cloud can be seen on radar.

(3) the responsibility of ATC if advised of the cloud by the pilot.

(4) a responsibility shared equally by the pilot and ATC.

9. You have been cleared to land in a gusty wind condition. You are concerned at the wind angle as indicated by the wind sock at the approach end of the runway, which you feel now favours another runway. You should:

(1) continue and land as you must obey the landing clearance.

(2) use full flaps and approach at a reduced approach speed.

(3) alter heading and land on another runway which is more into wind.

(4) overshoot and request an into wind runway.

10. If visible, wing tip vortex circulation viewed from the rear would appear to be:

(1) anti-clockwise around both wing tips.

(2) clockwise around both wing tips.

(3) anti-clockwise around the left wing tip and clockwise around the right wing tip.

(4) clockwise around the left wing tip and anti-clockwise around the right wing tip.

11. On being cleared to the circuit VFR, aircraft will normally join the airport traffic circuit at 1000 feet above ground. This may not always be possible because of:

(1) the existence of a special procedures NOTAM which provides for a different circuit altitude.

(2) weather conditions may be such as to necessitate a circuit height lower than 1000 feet.

(3) the possibility of a "straight in" clearance to the airport in which case the final leg would normally be entered at less than 1000 feet.

(4) all of the above are correct.

12. A pilot, on final approach, is requested by ATC to reduce airspeed. He should:

(1) comply, giving due consideration to safe minimum maneuvring speed of his aircraft.

(2) reduce airspeed below normal approach speed range.

(3) overshoot and rejoin circuit.

(4) acknowledge transmission, and execute a 360° turn.

13. You have been cleared to taxi to the runway in use. To get there you must cross two taxiways and one runway. Your clearance allows you to:

(1) taxi to position on the runway in use.

(2) taxi to hold short of the runway in use but get clearance to cross each taxiway and runway en route.

(3) taxi to hold short of the runway in use, but get clearance to cross the other runway.

(4) taxi to, but hold short of runway in use.

14. Responsibility for anticipating and avoiding wake turbulence is:

(1) the sole responsibility of the pilot.

(2) the sole responsibility of ATC.

(3) the responsibility of the pilot only if not informed by ATC of the possibility of wake turbulence.

(4) a responsibility shared by both the pilot and ATC.

15. Available information indicates that hazardous wake turbulence created by large aircraft in still air:

(1) dissipates immediately.

(2) dissipates rapidly.

(3) may persist for 2 minutes or more.

(4) persists indefinitely.

16. An aircraft is "cleared to the circuit" where a left hand circuit is in effect. Without further approval from ATC a right turn may be made to:

(1) enter the circuit from the upwind side, crosswind, or on the downwind leg.

(2) enter the base leg.

(3) enter the final leg.

(4) descend on downwind leg.

17. You are well advanced on final approach, and the runway is clear of traffic. You have not received landing clearance and are unable to establish contact with the tower. You should:

(1) continue and land as the runway is clear.

(2) continue and land as you assume the tower controller is busy with other duties for the moment.

(3) continue and land because with a runway clear of traffic, landing clearance is just a formality.

(4) pull up and make another circuit.

18. Which statement concerning wing tip vortices is false:

(1) they are caused directly by "jet wash".

(2) these vortices normally settle below and behind the aircraft.

(3) with a light crosswind, one vortex can remain stationery over the ground for some time.

(4) lateral movement of vortices, even in a no wind condition, may place a vortex core over a parallel runway.

19. You are cleared for take-off immediately following the low approach (200 feet altitude) and overshoot of a large aircraft. You should:

(1) take-off immediately in order not to inconvenience aircraft which are waiting in line to take-off after you.

(2) taxi to position on runway and wait until it is safe to take-off.

(3) decline take-off clearance and advise tower of your intentions.

(4) take-off and do an immediate steep turn left or right away from the runway in order to avoid the wake turbulence of the overshooting aircraft.

20. When filing a stop-over flight plan for a VFR flight the total elapsed time to be entered is:

(1) the total estimated elapsed time for all legs.

(2) the total estimated elapsed time for all legs plus the duration of the stop-overs.

(3) the estimated elapsed time to the first landing plus stop-overs.

(4) total estimated elapsed time for all legs, plus stop-over plus 45 minutes.

21. The rate of roll generated in vortices trailing the wing tips of a large jet aircraft such as a DC-8, can be up to 80 degrees per second. Compared to the roll rate capability of the average light training aircraft using full aileron, this rate is:

(1) less than the average light aircraft maximum roll rate capability.

(2) the same as the average light aircraft roll rate.

(3) approximately twice the rate of roll of which the average light aircraft is capable.

(4) four times the average light aircraft roll rate.

22. How is a VFR stop-over flight plan indicated on the flight plan form:

(1) by repeating name of stopping point in "route" column and indicating duration of stop-over in "other information" column.

(2) by simply indicating "stop-over" in "other information" column.
(3) by including stop-over duration in "elapsed time" box as ATC automatically checks time between points.
(4) same as any VFR flight plan if stop-over time does not exceed 30 minutes at each point.

23. On final approach the tower issues this clearance, "Cleared to land and check gear down". With respect to your landing gear, this means:

(1) tower confirms your gear is down and locked.
(2) tower is telling you the gear is down but does not appear fully locked.
(3) tower is ordering you to lower your gear at this time.
(4) tower is reminding you to lower the gear before landing.

24. When an arriving aircraft is "cleared to the circuit" by the controller, the pilot should interpret this to mean that he should:

(1) join the circuit on the downwind leg.
(2) join the circuit from the upwind side of the runway in all cases.
(3) join on base if convenient.
(4) proceed straight in if able.

25. If a pilot finds all or part of an ATC clearance unacceptable he should:

(1) acknowledge the clearance and act only on that portion which is acceptable.
(2) accept the clearance anyway.
(3) refuse the clearance giving reasons for the refusal.
(4) acknowledge the clearance but take no action.

26. A pilot wishing to make an intersection take-off may request such permission from the tower. If authorized, the pilot must bear in mind that:

(1) the remaining runway length will always be given by the controller.
(2) it is the pilot's responsibility to ensure that the remaining runway length is sufficient for take-off.
(3) the controller will ensure that the remaining runway length is sufficient for take-off.
(4) any noise abatement procedures for that runway are automatically cancelled.

27. Once established on the downwind leg the pilot should advise ATC accordingly. If there is other traffic in the circuit, ATC will then:

(1) clear him to land.
(2) inform the pilot of his number in the approach sequence or other appropriate instructions.
(3) give the pilot the runway, wind and altimeter.
(4) advise the pilot of all other circuit traffic.

28. The ceiling and visibility at your destination airport is as follows: 1000 feet overcast, visibility 3 miles. With regard to your circuit altitude you should:

(1) fly 1000 feet above airport elevation.
(2) fly 500 feet below the cloud base.
(3) avoid the Control Zone as the weather is below VFR.
(4) request special VFR into the Control Zone.

29. You receive the following transmission from the control tower **"Alfa Bravo Charlie Cleared to Land, Turn Right at the First Intersection"**.

After touchdown, you consider this turn to be only marginally possible due to the short distance between your touchdown point and the turn off. You should:

(1) attempt to turn off as requested even though you consider that your speed is too high to safely accomplish the turn.
(2) complete a touch and go because you do not believe it possible to safely accomplish the requested turn off.
(3) land and turn off at the closest intersection possible commensurate with safety.
(4) land normally, do a 180° turn and taxi back to clear the runway at the required intersection.

30. Vortices from the wing tips of heavily loaded large aircraft expand and impinge on each other towards the centre of the wake. A light aircraft caught between the vortices experience violent vertical downward currents of air that exceed the climb capability of the aircraft. The correct response to fill in the blank space is:

(1) can be expected to
(2) might possibly
(3) could never
(4) will occasionally

31. The pilot of a light aircraft approaching to land immediately following a large aircraft should plan his approach (other circumstances permitting) to remain:

(1) above the approach path of the large aircraft and land beyond its touch down point.
(2) on the upwind side of the large aircraft approach path and land on the upwind side of the runway.
(3) below the approach path of the large aircraft and land just prior to its touch down point.
(4) on the normal approach path for your aeroplane but at higher approach speed, as there is only a slight chance of encountering hazardous turbulence.

32. While flying VFR in an Extended Terminal Control Service Area, you have advised ATC you are maintaining a specific heading. If you continue on this heading, you can see that your flight path will, in your opinion, take you dangerously close to another aircraft which is on a converging course. You should:

(1) alter heading to avoid the other aircraft and advise ATC.
(2) maintain the specified heading on the assumption that separation will be provided by the controller.
(3) change altitude as required to avoid the other aircraft.
(4) maintain the specified vector because it would violate the Air Regulations to do otherwise.

33. An Air Traffic Control "instruction"

(1) is the same as an Air Traffic Control "clearance"
(2) must be complied with when received by the pilot to whom it was directed providing the safety of the aircraft is not jeopardized.
(3) must be "read back" in full to the controller and confirmed before becoming effective.
(4) is in effect "advice" provided by ATC and does not require acceptance or formal acknowledgement by the pilot concerned.

34. A VFR flight plan must be closed by the pilot:

(1) by advising ATC either directly or via a communications base of his arrival time.
(2) except at airports served by a control tower in which case the tower will close the flight plan.
(3) by parking his aircraft in close proximity to the tower.
(4) by filing a return flight plan.

35. Your initial radio contact with the control tower shall always be:

(1) prior to approaching within 5 miles of an airport.
(2) prior to approaching within 10 miles of an airport.
(3) prior to entering the Control Zone.
(4) immediately prior to joining the circuit.

36. A pilot on a Special VFR flight has been cleared for a

"straight in" approach. Because of his low altitude and poor visibility, he is concerned about the exact location of a radio mast in the vicinity. The responsibility for avoiding this obstruction is:

(1) the responsibility of the pilot.
(2) the responsibility of the tower controller as he is aware of the obstruction.
(3) the responsibility of ATC as the pilot has been given Special VFR clearance.
(4) the responsibility shared equally by the pilot and the tower controller as the aircraft is within a Control Zone.

37. A pilot on a VFR flight has been assigned a radar vector, specific heading or routing instruction by Air Traffic Control. However, continued flight in this direction will appear to bring the aircraft dangerously close to a T.V. Tower in the distance. The pilot should:

(1) continue on this heading as ATC is aware of the obstruction and will issue heading changes as necessary.
(2) advise ATC of the situation and request alternate instructions.
(3) continue, because to do otherwise would be a violation of the Air Regulations.
(4) fly a 2 minute triangle pattern to the right.

38. Your destination airport is one from which a Special Procedures NOTAM has been published, which states that the circuit height is 1500 feet ASL. The airport elevation is 400 feet ASL. The ceiling is 1000 feet overcast and the visibility is 3 miles. Under these circumstances your circuit altitude should be:

(1) 1100 feet above the airport elevation.
(2) 1000 feet above the airport elevation.
(3) 500 feet below cloud base.
(4) 1500 feet above sea level.

39. A pilot on a Special VFR flight has been cleared to the circuit. Ahead and below his flight path there is an overcast layer of stratus cloud. The responsibility of remaining clear of cloud is:

(1) the responsibility of the pilot.
(2) the responsibility of the tower controller as it is within a Control Zone.
(3) the responsibility of ATC because weather is below VFR.
(4) the responsibility is shared equally by the pilot and ATC.

40. A departing VFR aircraft will normally clear tower frequency when:

(1) an altitude of 1000 feet above ground has been reached.
(2) the flight has left the appropriate control area.
(3) the flight is 10 minutes flying time from the airport.
(4) the flight is clear of the control zone.

41. A pilot on a VFR flight has been assigned a radar vector, specific heading or routing instruction by Air Traffic Control. Ahead, on his flight path, is a hill with a large tower. The responsibility for avoiding this obstruction is:

(1) the sole responsibility of the pilot.
(2) the responsibility of Air Traffic Control as the obstruction can be seen on radar.
(3) a responsibility shared equally by the pilot and ATC.
(4) the responsibility of ATC if the pilot advised his altitude.

42. A pilot on a VFR flight has requested Radar Assistance and is flying a radar vector, provided by ATC, to the nearest airport. Ahead, and below is a solid overcast cloud condition. The pilot should:

(1) maintain heading and altitude as it is a clearance issued by ATC.
(2) maintain heading and altitude because ATC knows of the cloud and will issue further instructions.
(3) climb above the cloud and fly "1000' on top".
(4) alter course as necessary to remain VFR and advise ATC.

ANSWERS TO THE QUESTIONS

1. (2)
2. (2)
3. (2)
4. (2)
5. (4)
6. (4)
7. (2)
8. (1)
9. (4)
10. (4)
11. (4)
12. (1)
13. (4)
14. (1)
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36. (1)
37. (2)
38. (3)
39. (1)
40. (4)
41. (1)
42. (4)

CONTROLLED VFR

A special endorsement to a Private or Commercial Pilot's Licence is required in Canada to fly "Controlled VFR" in the Block Airspace above 9,500 ft. east of the Rockies, or 12,500 ft. west of the Rockies.

The following texts will prove useful references when preparing to write the exam.: *Canada Air Pilot, Air Navigation Radio Aids, Flight Information Manual, ANO Series V, No. 2 and Series V, No. 11, Air Regulations and Air Traffic Control Manual, Chapter C,* obtainable from the DoT, Ottawa.

The examination consists of questions of a general nature on navigation, radio navigation, radio-telephony, and communication facilities and of questions having special reference to the Block Airspace such as those below.

1. What information should a Controlled VFR Flight Plan contain?

Aircraft registration. Type. Point of departure. Altitude and route. Point of first intended landing. Time of departure. True airspeed. Estimated elapsed time. Radio frequencies. Number of persons on board. Pilot's name. Fuel on board. Aircraft owner. Aircraft colour. Pilot's license number.

2. At what height would you normally request a clearance to enter the Block Airspace?

At approximately 8500 feet (east of the Rockies) or at 11,500 feet (west of the Rockies).

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ABBREVIATIONS

The ABC's spelled out in this index apply only to the abbreviations used in this manual.
They do not, by any manner of means, attempt to cover the complete ABC lingo of aviation.

A or AST—Atlantic Standard Time
ADCUS—Advise Customs
ADF—Automatic Direction Finder.
ADIZ—Air Defence Identification Zone.
AGL—Above Ground Level.
ANO—Air Navigation Order.
ARTC—Air Route Traffic Control.
ASL—Above Sea Level.
ATC—Air Traffic Control.
ASR—Airport Surveillance Radar.
AUW—All-up-weight.

BFO—Beat Frequency Oscillator.
BHP—Brake Horse Power.
BMEP—Brake Mean Effective Pressure.

C or CST— Central Standard Time.
C—Celsius
CADIZ—Canadian Air Ident. Zone.
Can.—Canada.
CAS—Calibrated Airspeed.
CAVU—Ceiling and Visibility Unlimited.
CG—Centre of Gravity.
CLC—Course Line Computer
CP—Centre of Pressure.
CVFR—Controlled VFR.
CVR—Controlled Visual Rules.
CW—Continuous Wave (Wireless Key).

DCS—Double Channel Simplex.
DCD—Double Channel Duplex.
DEWIZ—Distant Early Warning Identification Zone.
D/F—Direction Finder.
DME—Distance Measuring Equipment.
DOT—Department of Transport.
D/R—Dead Reckoning.
DVFR—Defence Visual Flight Rules.

E or EST—Eastern Standard Time.
EHF—Extremely High Frequency
ETA—Estimated Time of Arrival.

F—Fahrenheit.
FAA—Federal Aviation Agency. (U.S.)
FAR—Federal Air Regulations. (U.S.)
FL—Flight Level.

FSS—Flight Service Station. (U.S.)
FVFR—VFR Flight Following Service.

GCA—Ground Controlled Approach.
GHA—Greenwich Hour Angle.
GMT—Greenwich Mean Time.

HF—High Frequency.
Hg.—Inches of Mercury.
HP—Horse Power.
Hrs.—Hours.

IAS—Indicated Airspeed.
ICAN—International Committee for Air Navigation.
ICAO— International Civil Aviation Organization was established in 1944 as the official world wide medium through which international standards and procedures are developed in technical matters, safety, orderly economic growth and air law. Headquarters are in Montreal.
IFR—Instrument Flight Rules.
ILS—Instrument Landing System.
ISA—International Standard Atmosphere.
KHz—Kilohertz.
Kts.—Knots.

Lat.—Latitude.
L/MF—Low Medium Frequency.
LHA—Local Hour Angle.
Long.—Longitude.

M or MST—Mountain Standard Time.
MAC—Mean Aerodynamic Chord
MHz—Megahertz
MEA—Minimum Enroute Altitude.
Met.—Meteorology.
Min.—Minutes.
MOCA—Min. Obstruction Clearance Altitude.
Mph—Miles per Hour
MSL—(Above) Mean Sea Level

N.miles—Nautical Miles.
Nav.—Navigation.
Navaid—Navigation Aid.

NORDO—No Radio.
NOTAMS—Notices to Airmen. They are broadcast by Aeradio Stations and are also published in printed form. They convey information of special import regarding the facilities in their respective areas.
NT Error—Northerly Turning Error.

PAL—Peripheral Station.
PAR—Precision Approach Radar.
P or PST—Pacific Standard Time.
PIREPS—Pilot Reports.

QNH—The Local Current Altimeter Setting.
RAPCON—Radar Approach Control.
RONLY—Receiver Only.
ROTATE— A word used to indicate one of several take-off sequences. The terms stems from "rotate about the lateral axis of an airplane" and applies to a change of attitude during take-off.

SCS—Single Channel Simplex.
SHA—Sidereal Hour Angle.
S.miles—Statute Miles.
SSB—Single Side Band.
Standard Atmosphere—29.92 inches of mercury at 15°C at sea level.

TACAN—Tactical Air Navigation.
TAS—True Airspeed.

UHF—Ultra High Frequency.
US—United States

V—Victor Airway (VOR).
VFR—Visual Flight Rules.
VHF—Very High Frequency
VORTAC—VOR—TACAN.
VOR—VHF Omnidirectional Range.

Wx—Weather.

XC-Cross-Country.

Z—Greenwhich Mean Time.

THE V SPEEDS

V_A — design maneuvering speed.
V_B — design speed for maximum gust intensity.
V_C — design cruising speed.
V_D — design diving speed.
V_{DF}/M_{DF} — demonstrated flight diving speed.
V_F — design flap speed.
V_{FC}/M_{FC} — maximum speed for stability characteristics.
V_{FE} — maximum flap extended speed.
V_H — maximum speed in level flight with rated rpm and power.
V_{LE} — maximum landing gear extended speed.
V_{LO} — maximum landing gear operating speed.
V_{LOF} — lift-off speed.
V_{MC} — minimum control speed. The minimum speed at which it is possible to control the airplane in the air, with one engine inoperative and the other engine(s) at take-off thrust.
V_{MCA} — minimum control speed in the air in a take-off configuration.
V_{MCG} — minimum control speed on the ground. The minimum speed at which it is possible to suffer an engine failure on take-off and maintain control of the airplane.
V_{MCL} — minimum control speed in the air in an approach or landing configuration with an engine inoperative.
V_{MO}/M_{MO} -- maximum operating speed. The maximum permitted speed for all operations.
V_{MU} — minimum unstick speed. The minimum speed at which the airplane can be lifted off the runway without displaying any hazardous flight characteristics.
V_{NE} — never exceed speed.
V_{NO} — normal operating speed. The maximum permitted speed for normal operations.
V_{RA} — rough air speed. The recommended speed for flight in turbulence.
V_R — rotation speed.
V_S — stall speed. The minimum steady flight speed at which the airplane is controllable.
V_{SL} — stall speed obtained in a specified configuration. Power-off stall speed ("Clean").
V_{SO} — stall speed in landing configuration.
V_X — speed for best angle of climb.
V_Y — speed for best rate of climb.
V_1 — critical engine failure speed. Take-off decision speed. The speed above which the take-off is continued, and below which the take-off is abandoned in the event of an engine failure.
V_2 — take-off safety speed. Take-off and climb speed.
V_{2min} — minimum take-off safety speed.

TABLE OF DIMENSIONAL UNITS

	Column I	Column II	Column III	Column IV
Dimensions	ICAO Table	Blue Table	United States and Alaska	Canada
Distance	Nautical Miles and Tenths	Nautical Miles and Tenths	Nautical Miles and Tenths	Nautical Miles and Tenths
Altitudes, Heights, Elevations and Dimensions on Aerodromes and Short Distances	Metres	Feet	Feet	Feet
Horizontal Speed	Knots	Knots	Knots	Knots
Vertical Speed	Metres Per Second	Feet Per Minute	Feet Per Minute	Feet Per Minute
Wind Speed	Knots	Knots	Knots	* Knots
Wind Directon for Landing and Taking Off	Degrees Magnetic	Degrees Magnetic	→Degrees (A) Magnetic for Local Aerodrome (B) True for Other Aerodromes	Degrees Magnetic
Wind Direction for All Other Purposes	Degrees True	Degrees True	Degrees True	Degrees True
Cloud Altitude and Height	Metres	Feet	Feet	Feet
Visibility	Kilometers (or Meters)	Nautical Miles (or Yards)	* Statute Miles	* Statute Miles
Altimeter Setting	Millibars	Millibars	* Inches of Mercury	* Inches of Mercury and Millibars
Temperature Surface Upper Air	Celsius	Celsius	* Fahrenheit * Celsius	* Celsius
Weight	Kilogrammes	Pounds	Pounds	Pounds
Time	Hours and Minutes the Day of 24 Hours Beginning at Midnight Greenwich Mean Time	Hours and Minutes the Day of 24 Hours Beginning at Midnight Greenwich Mean Time	* 24 Hour Clock GMT in Areas Under U.S. Jurisdiction	Hours and Minutes the Day of 24 Hours Beginning at Midnight Greenwich Mean Time

Note:—1. The U.S. will use the BLUE table with the difference as noted (*) in column III.
2. Dependent territories use the same table as mother country unless otherwise indicated.

CONVERSION TABLES and FACTORS

TEMPERATURE

C°	F°	C°	F°
235	455	90	194
230	446	85	185
225	437	80	176
220	428	75	167
215	419	70	158
210	410	65	149
205	401	60	140
200	392	55	131
195	383	50	122
190	374	45	113
185	365	40	104
180	356	35	95
175	347	30	86
170	338	25	77
165	329	20	68
160	320	15	59
155	311	10	50
150	302	05	41
145	293	00	32
140	284	-05	23
135	275	-10	14
130	266	-15	05
125	257	-20	-04
120	248	-25	-13
115	239	-30	-22
110	230	-35	-31
105	221	-40	-40
100	212	-45	-49
95	203	-50	-58

MULTIPLY	BY	TO OBTAIN
Celsius	9/5 then add 32	Fahrenheit
Centimeters	0.3937	Inches
Fahrenheit	Subtract 32 then x 5/9	Celsius
Fathoms	6	Feet
Feet	0.30481	Meters
Gallons (Imp.)	1.20095	Gallons (U.S.)
” ”	4.54597	Litres
” (U.S.)	0.83268	Gallons (Imp.)
” ”	3.785332	Litres
Inches of Hg.	33.86395	Millibars
” ” ”	0.491174	Lbs. sq. inch
Inches	25.4	Millimeters
Kilograms	2.20462	Pounds
Kilometers	0.62137	Miles (Statute)
”	0.539553	” (Nautical)
Lbs. sq. inch	2.036	Inches of Hg.
Litres	0.219975	Gallons (Imp.)
”	0.264178	” (U.S.)
Meters	3.28083	Feet
Miles (Nautical)	76/66	Miles (Statute)
” ”	1.853249	Kilometers
” (Statute)	66/76	Miles (Nautical)
” ”	1.609347	Kilometers
Millibars	0.029531	Inches of Hg.
”	0.7501	Millimeters of Hg.
Millimeters	0.03937	Inches
” of Hg.	1.33315	Millibars
Pounds	0.453592	Kilograms

THE Q CODE

QDR— **Give me my Mag. Bearing from you.**

QDM— **Give me the Mag. Heading to steer, with zero wind**

QTE— **Give me my True Bearing from you.**

QTF— **What is my position, by D/F Fix?**

QNE— **With altimeter setting 29.92, what will my altimeter read on landing at .... at ....Hrs.**

QNH— **Give me the altimeter setting that will record the elevation of your station if I land there.**

EQUIVALENTS

1mile (statute) = 5280 feet
= 1609.35 meters
1 mile (nautical) = 6080 feet
= 1825 meters
1 Kilometer = 3280.83 feet
= 1000 meters
1 Stone = 14 pounds
1 hundredweight (short) = 100 pounds
1 hundredweight (long) = 112 pounds
1 ton (short) = 2000 pounds
= 907.19 Kilograms
1 ton (long) = 2240 pounds
= 1016.05 Kilograms
1 ton (metric) = 2204.62 pounds
= 1000 Kilograms